WATER RESOURCES OF THE LAKE ERIE-NIAGARA AREA, NEW YORK

A PRELIMINARY APPRAISAL

By A. M. La Sala, Jr., W. E. Harding, and R. J. Archer, U. S. Geological Survey

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY — WATER RESOURCES DIVISION

NEW YORK STATE WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

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U. S. Geological Survey
in cooperation with the
New York Division of Water Resources
for the
ERIE – NIAGARA BASIN BOARD

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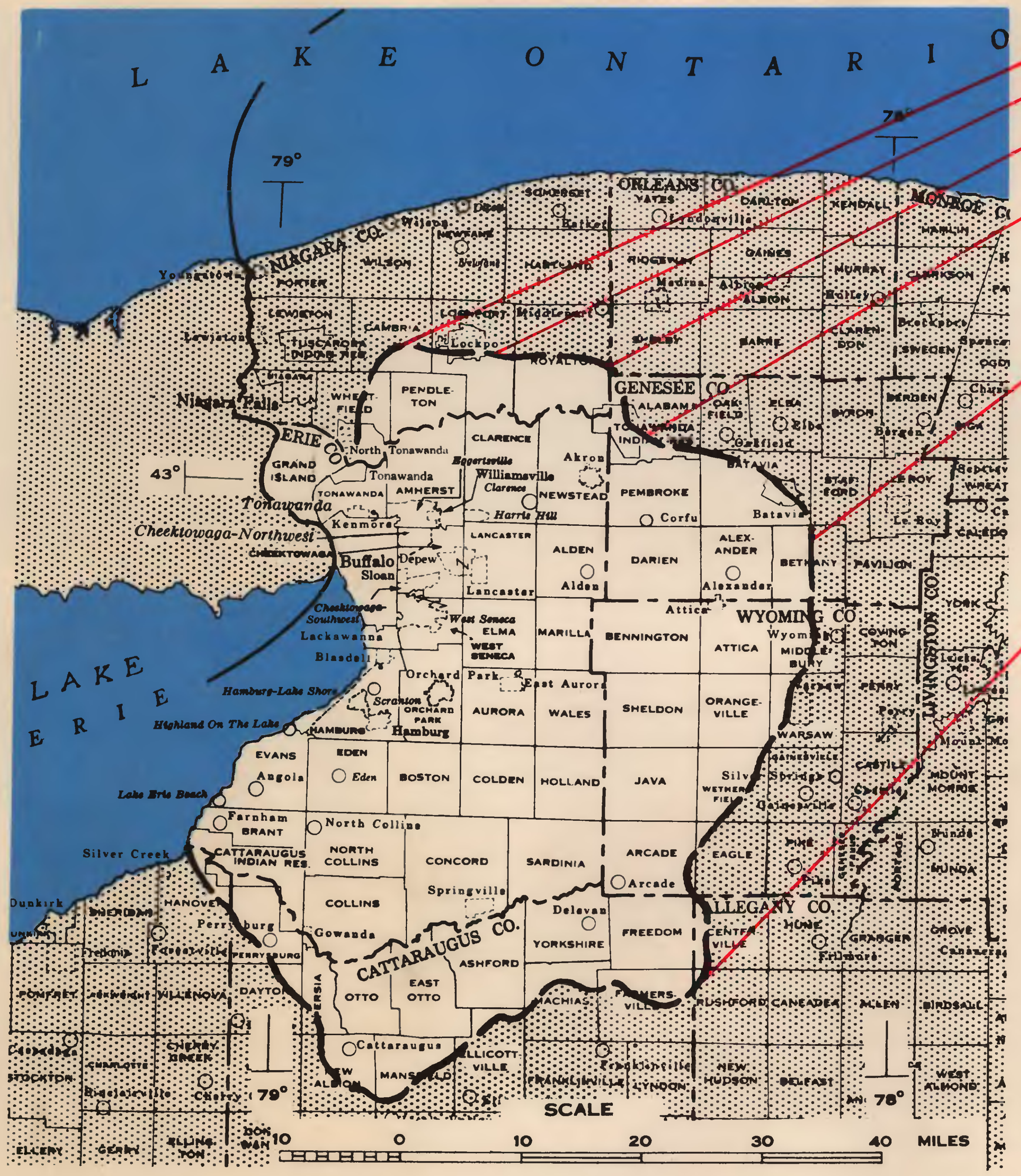


SYMBOLS

— - — - —	COUNTY
————	MINOR CIVIL DIVISION
- - - - - -	INCORPORATED OR UNINCORPORATED PLACE NOT A MINOR CIVIL DIVISION
o	INCORPORATED OR UNINCORPORATED PLACE WITH FEWER THAN 2,500 INHABITANTS

TYPE STYLES

WASHINGTON	COUNTY
WASHINGTON	MINOR CIVIL DIVISION
Washington	INCORPORATED PLACE WITH 50,000 OR MORE INHABITANTS
Washington	INCORPORATED PLACE WITH FEWER THAN 50,000 INHABITANTS
Washington	UNINCORPORATED PLACE

MINOR CIVIL DIVISIONS-TOWNS AND CITIES

(Adapted from 1960 map of New York, U.S. Bureau of the Census, 1961; scale about 1:750,000)

THIS AREA, of 2,000 square miles, has . . .

. . . A population of more than one million people, largely concentrated in northwestern part of area.

. . . Tremendous supplies of water available from Lake Erie and the Niagara River, and large supplies of good-quality water also available from streams and wells in the upper Cattaraugus Creek basin and in some other valleys in uplands part of region.

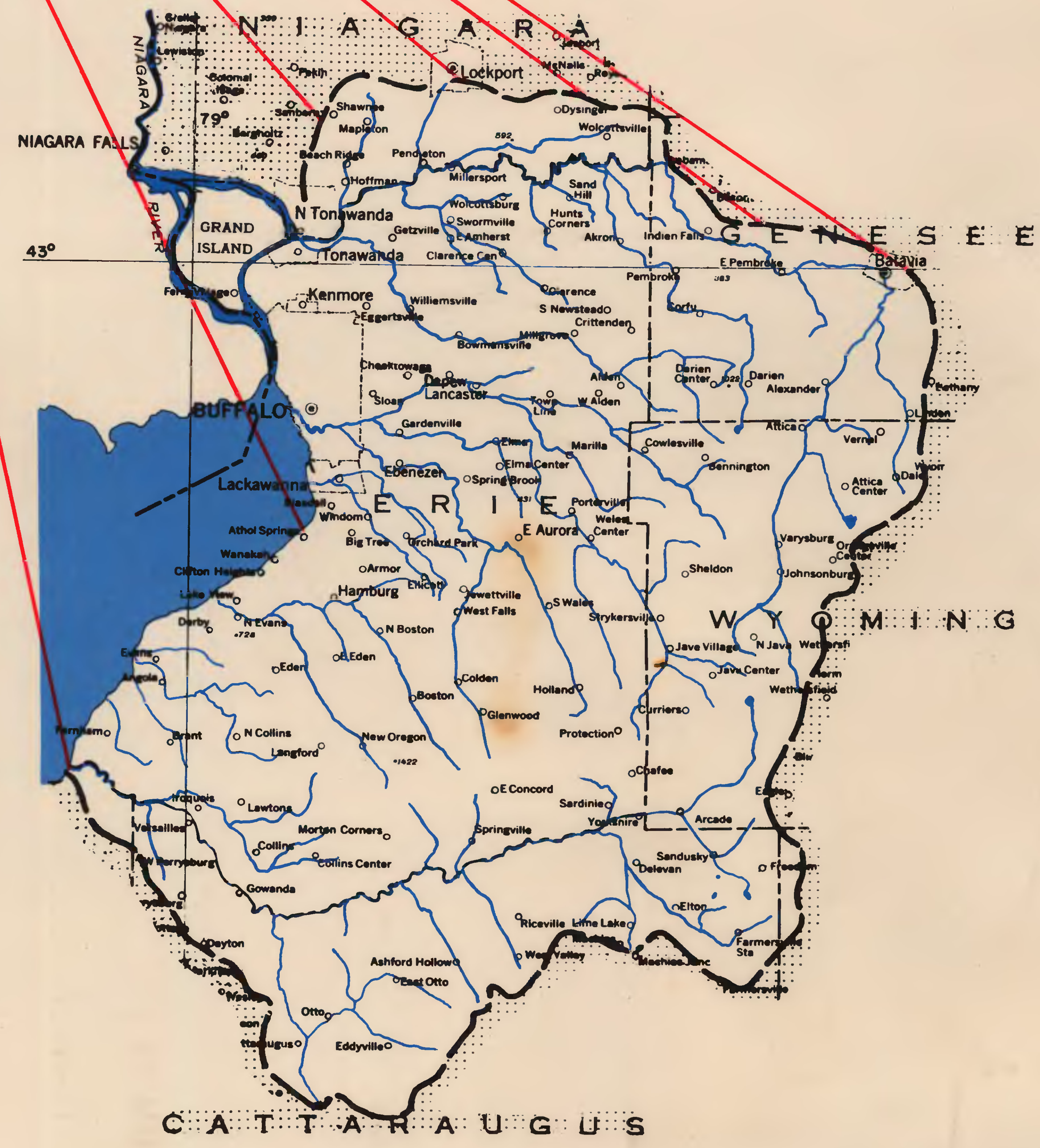
. . . Water highly mineralized in some northern parts of the region.

. . . Some water sources presently polluted.

. . . Spring and ice-jam floods on parts of many streams, including Scajaquada, Buffalo, Cattaraugus, Tonawanda, and Ellicott Creeks.

THIS REPORT discusses these and related water facts on the following seven sheets . . .

. . . A -- INTRODUCTION
B -- WATER PROBLEMS OF THE AREA
C -- FAVORABLE FEATURES OF THE AREA
D -- GROUND WATER AND GROUND-WATER DISCHARGE
E -- STREAMFLOW (including floods)
F -- CHEMICAL QUALITY OF WATER
G -- SEDIMENT IN STREAMS AND SUMMARY OF WATER RESOURCES



PRINCIPAL CITIES AND TOWNS, AND STREAMS
(Adapted from base map of New York, U.S. Geological Survey, 1956; scale 1:500,000)

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SHEET A — INTRODUCTION

WHY THIS APPRAISAL

The New York State Water Resources Planning Act (1959) enables the Water Resources Commission to cooperate with and assist local governments in water-resources planning studies. The Boards of Supervisors of Erie, Genesee, Wyoming, and Cattaraugus Counties applied for a study within the area shown on figure A-1, and the first Regional Water Resources Board within the State was established in January 1963. Known as the Erie-Niagara Basin Board and composed of local leaders representing various water-resources interests, the unsalaried Board is responsible for the conduct of the study and for the preparation of a comprehensive plan for the development, utilization, and control of the water resources of the basin. The plan that is finally evolved will become the official plan controlling all water and associated land-resources activities and developments in the region, after approval by the State Water Resources Commission. The enabling legislation provides that the State shall pay 75 percent and the petitioning counties 25 percent of the total cost of the study. The Water Resources Commission has directed the Division of Water Resources, Conservation Department, to provide technical services and to coordinate the overall study for the Board.

Data and detailed information on the water resources of the area are important first-order needs of the Board. To provide this information a cooperative investigation is being made, involving principally, the Water Resources Division of the U. S. Geological Survey, the Division of Environmental Health Services of the New York State Health Department, and the Division of Water Resources of the New York State Conservation Department. The cooperative activities of these three organizations are being coordinated throughout the study. The water-resources portion of the study has been divided into two phases. This report, which contains a preliminary appraisal, completes the U. S. Geological Survey's part of Phase 1. Phase 2 is scheduled for completion in June 1966, with the preparation of a comprehensive report by the Survey. The Health Department's contributions will be coordinated and included in the final comprehensive report.

This preliminary, or interim, report of December 1963, is designed to provide a well-rounded but limited description of the water resources of the region. Maximum use has been made of existing data collected by the Geological Survey and other Federal, State, and local agencies. However, early recognition of deficiencies in the available data demonstrated the need for additional information and some of the necessary data have been obtained. A number of questions must ultimately be answered: How much water is available? Where is it available? When is it available? What are its chemical characteristics? Who uses water and where? What is done with the water after use?

Data and information from the Geological Survey's "Phase 2" report on the water resources, when coupled with the economic base survey, and agricultural, industrial, urban, and other information, will provide the basis for evolving the comprehensive plan for the short- and long-range development of the water resources of the region.

WHAT ARE THE WATER RESOURCES OF THE AREA?

Water is constantly moving on and beneath the land surface and to and from the atmosphere. These movements are collectively referred to as the hydrologic cycle. Water is evaporated from the earth's surface, transported as clouds of water vapor, and returned to the earth as rain or snow. Part of the rain or melted snow runs off over the surface as overland flow and then as streamflow, part of it evaporates again to the atmosphere, and a part enters the ground. Some of the water which enters the ground is retained temporarily in the soil zone from which it is withdrawn by vegetation and returned to the atmosphere by the process of transpiration. The remainder seeps downward to the zone of saturation and becomes ground water. In the zone of saturation, water moves laterally and downward through the earth to points of discharge such as lakes, streams, springs, and wells. The circulation of water through the stream systems and through the ground is necessarily of great concern, because only from these parts of the hydrologic cycle can large quantities of water be obtained.

The Geologic and Topographic Framework

The land surface, and the rocks and unconsolidated deposits that underlie it, form the framework on and through which water moves in its endlessly repeated journeys from the land to the sea and back to the land. The form, structure, and composition of this framework have a considerable effect upon the movement, quantity, and quality of water available to man.

The Lake Erie-Niagara area straddles the boundary of two physiographic divisions of New York State -- the Erie-Ontario Lowlands, and the Appalachian Uplands (fig. A-1). Each of these physiographic divisions has fairly distinct topographic, climatic, and geologic characteristics, which in turn affect the occurrence of water in each region. The Erie-Ontario Lowlands is a plain which generally ranges from 600 to 700 feet above mean sea level. The surface of Lake Erie averages about 572 feet above sea level. The hilly terrain of the Appalachian Uplands rises rather abruptly from the lowlands to altitudes of about 1,500 feet in a few miles and increases toward the southwest and south, to about 2,000 feet.

Figure A-1.--Physiographic divisions and average annual precipitation in the Lake Erie-Niagara area (Precipitation data from Knox and Nordenson, 1955).

The bedrock of the area consists of shale, limestone, dolomite, and sandstone. They occur in beds that dip gently southward. Shale is the most widely distributed of these rocks.

Unconsolidated deposits overlie the bedrock. They consist of till, which is a mixture of clay, silt, sand, and larger rock fragments deposited by glacial ice; bedded sand and gravel deposited by glacial streams; and layered clay, silt, and fine sand deposited in glacial lakes.

Incoming Water - Precipitation

The Lake Erie-Niagara area is water rich. Average annual precipitation in the Lake Erie-Niagara area ranges from about 31 to 44 inches. In figure A-1, the lines of average annual precipitation show an increase in precipitation across the area from northwest to southeast. This increase correlates with a general rise in the land surface to the southeast and shows, in part, the effect of topography on precipitation. Moisture-laden airmasses generally move eastward across the area from Lake Erie. With movement inland, they are forced upward, become cooler, and precipitate much of their moisture as rain or snow.

The Stream Systems and Streamflow

The major streams in the Lake Erie-Niagara area rise in the Appalachian Uplands and flow into Lake Erie or the Niagara River. A broad dissected upland area forms a divide between the Cattaraugus Creek drainage basin and the drainage basins to the north -- Eighteenmile Creek, Buffalo River, and Tonawanda Creek basins. Cattaraugus Creek is the only major stream that flows in a westward direction through the uplands. The other major streams flow in a northerly or northwesterly direction through the uplands and turn west only on reaching the lowlands.

Although precipitation on the average, is relatively evenly distributed throughout the year, streamflow varies considerably. Figure A-2 shows the mean daily discharge in cubic feet per second per square mile (mean daily flow divided by drainage area) for two streams in the Lake Erie-Niagara area. Note that the runoff is high in March and April when water from melting snow is added to the water from rainfall. Then, through the summer, streamflow decreases because most of the water from summer rains is evaporated from land and water surfaces or is transpired by vegetation.

The major streams and their larger tributaries are perennial sources of water supply. The smaller streams and tributaries, particularly those in the lowlands, dry up or are reduced to a trickle during the late part of most summers, except during storm periods.

Overland flow. -- Overland flow is the part of the precipitation that moves on the land surface to the streams. The streams generally discharge most of it from the area within a few days following a rain storm. A significant amount of the overland flow can be used only if reservoirs are available to store it.

The amount and rate of overland flow vary widely from one part of the area to another because of the great differences in topography and geology from one place to another. The flow runs off at a high rate on hills and slopes underlain by bedrock and till, the characteristic terrain of the Appalachian Uplands. Overland flow is also relatively great in areas of bedrock veneered with till and fine-grained deposits forming expanses of the Erie-Ontario Lowlands. However, the water in the lowlands moves off more slowly than in the hilly areas. Sand and gravel deposits, which underlie parts of the lowlands and large parts of the valleys of the uplands, shed proportionately less of the precipitation as overland flow than do the other types of glacial deposits and rocks.

How Ground Water Occurs

The bedrock and unconsolidated deposits are reservoirs for the storage of ground water -- the water that fills the openings in the rocks and deposits in the zone of saturation. Water enters the ground-water reservoirs by infiltration at the surface. The more water that infiltrates, the less will be the overland flow. However, ground water eventually seeps

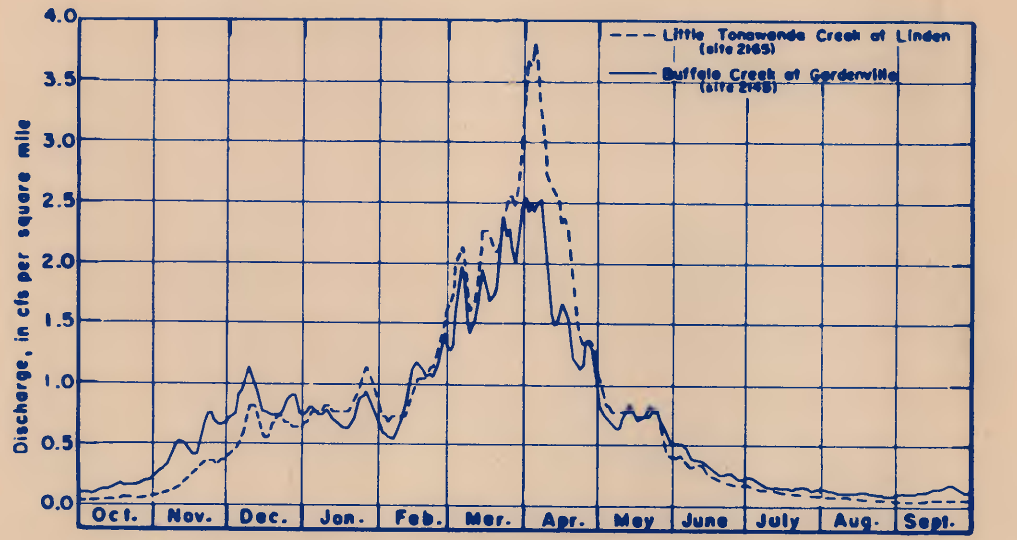

Figure A-2.--Daily mean discharge of Little Tonawanda Creek at Linden (1929-58) and of Buffalo Creek at Gardenville (1939-58), in cubic feet per second per square mile. (The plotted points represented by the lines above are actually "5-day moving averages" of daily mean discharges.)

into the streams and sustains their flow in periods of dry weather. Water is also withdrawn from the ground through wells and springs.

The size and interconnection of openings in a rock or unconsolidated deposit determine the efficiency of a ground-water reservoir. Coarse sand and gravel deposits contain numerous large pore spaces through which ground water moves freely. In contrast, till and fine-grained deposits -- clay, silt, and fine sand -- have small pore spaces, which transmit water very slowly. Therefore, the yields of wells in sand and gravel deposits are many times greater than those in till and fine-grained deposits. The bedrock contains water in fractures and openings between layers. In the northern part of the area, solution of limestone, dolomite, and other soluble rocks has widened the fractures and openings, improving the water-bearing properties of the bedrock. In the southern part of the area the lack of readily soluble materials has generally prevented the widening of the usually small openings in the rocks. Thus, the bedrock in the northern part of the area provides larger yields to wells than that in the southern part.

What Affects the Chemical Quality of Water?

Water contains dissolved solids derived from a variety of sources. Precipitation falling through the air dissolves the gases of the atmosphere as well as materials present in smoke and dust. Precipitation falling through the industrial smoke that drifts eastward from the Buffalo area is relatively high in dissolved solids. Overland flow dissolves solids from the soils and rocks over which it passes. Water that infiltrates the ground dissolves additional constituents from the soil and rocks. Limestone, dolomite, and other soluble rocks contribute particularly high concentrations of dissolved solids to water. Industrial and domestic wastes are other sources of dissolved constituents.

At floodflow, water in streams reflects the chemical constituents derived from the atmosphere by precipitation and from the land surface by overland flow. At low sustained flows during the summer, the water in streams reflects the quality of the ground water seeping or flowing into them.

Sediment in Streams

The streams transport sediment which is derived from the rocks and soils. Part of the sediment is eroded from the banks of streams, and part is washed off slopes by overland flow. The greatest quantity of sediment is transported when the streams are in flood during the spring thaw and following intense rain storms. Only very small amounts are carried by streams during periods of low flow.

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Reference cited on this sheet:

Knox, C. E., and Nordenson, T. J., 1955, Average annual runoff and precipitation in the New England-New York area: U.S. Geol. Survey Hydrologic Investigations Atlas HA-7.

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SHEET B — WATER PROBLEMS OF THE AREA

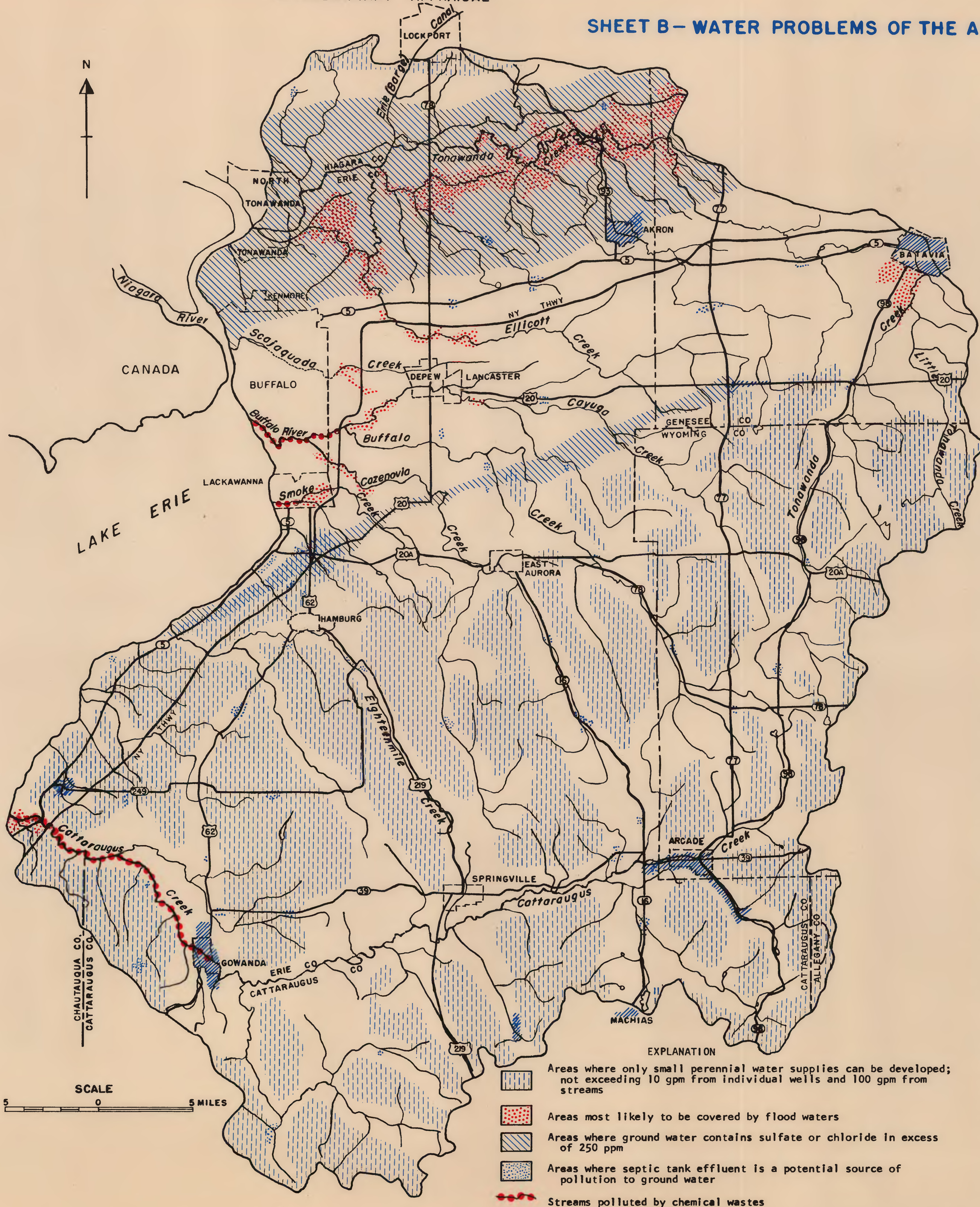

Figure B-1.--Areas having problems of water quantity or water quality.

EXPLANATION

Areas where only small perennial water supplies can be developed; not exceeding 10 gpm from individual wells and 100 gpm from streams

Areas most likely to be covered by flood waters

Areas where ground water contains sulfate or chloride in excess of 250 ppm

Areas where septic tank effluent is a potential source of pollution to ground water

Streams polluted by chemical wastes

Water-supply systems with sources which are inadequate or inadequately developed; maximum use approximates amount of water produced

(The areas not covered by any of the above symbols do not generally have the water problems noted above.)

A REVIEW OF THE PROBLEMS

Both natural and manmade conditions cause prolems affecting the availability and use of water. The adjacent map illustrates a few of the more widespread and important problems. These problems are primarily a result of the uneven areal and seasonal distribution of water, the poor chemical quality of the water in some areas, and the pollution of water by industrial and domestic wastes.

Uneven Areal Distribution of Water

The area is divisible into two parts on the basis of the availability of water. Large to moderate supplies of water are available in the northern part of the area and in the valleys of the Appalachian Uplands (fig. A-1). The supplies can be obtained from the major streams or from wells in bedrock in the northern part of the area and in sand and gravel deposits in the valleys of the upland region (figs. C-1 and D-1).

On the other hand, the hills of the uplands and part of the lowlands bordering Lake Erie are "poor" in water resources. These areas are underlain by rocks and glacial deposits that generally will yield no more than 10 gpm (gallons per minute) to individual wells. These same areas are drained by streams that either dry up or have sustained dry-weather flows of less than 100 gpm. The approximate extent of these areas where only small perennial water supplies can be developed is shown on figure B-1.

Uneven Seasonal Distribution of Water

The uneven seasonal distribution of water is one of the most serious problems in the area. It is most apparent in streams which may overflow their banks and damage property extensively in March and literally be reduced to a trickle in September.

Floods in the area are caused both by large stream discharges and by ice jams. Some flooding occurs on all major streams one or more times in the spring when large discharges are caused by the combined effect of rain and melting snow. The spring floods generally affect only small strips of floodplain on most streams, but large areas along Tonawanda and Ellicott Creeks are usually flooded (fig. B-1).

Localized flooding is sometimes caused by intense summer rainstorms. Such flooding usually occurs on the small streams near the location of the most intense rainfall. Local flooding on small streams generally does not cause a flood on the larger streams into which the small streams flow. Flooding from local storms sometimes passes relatively unnoticed in the Lake Erie-Niagara area, unless the storm occurs over a populated area. Such a summer storm on August 7, 1963, caused the worst flood in the history of Buffalo and adjacent Cheektowaga, as a result of the record high levels of Scajaquada Creek. Ellicott and Cayuga Creeks that lie north and south, respectively, of Scajaquada Creek, and are much larger, did not flood during this storm.

Floods caused by ice jams that sometimes follow the sudden breakup of ice, occur on the lower reaches of Cattaraugus and Smoke Creeks and on the Buffalo River and the lower reaches of its tributaries. Serious ice-jam flooding is not dependent upon very high stream discharges. An ice jam at the mouth of Cattaraugus Creek caused a flood of disastrous proportions in March 1963, although the streamflow at that time was not unusually large.

In contrast to seasonally high stream discharges in the spring, streamflow decreases to low rates in the late summer and early autumn. Many of the small streams then have little or no flow (fig. D-1), except following a locally intense rainfall. Problems of water supply arise as streamflow decreases. For example, the summer flow of Tonawanda Creek has proven inadequate for the Batavia municipal supply, which has recently been augmented by development of a ground-water supply.

Chemical Quality of Water Problems

High concentrations of sulfate and chloride in ground water are a problem in parts of the area. Ground water high in sulfate and chloride occurs in bedrock that underlies a broad belt across the northern part and a narrower belt across the central part of the area (fig. B-1). The bedrock underlying the northern belt is the Salina Group (fig. D-2), from which large quantities of ground water are discharged to Tonawanda Creek. The ground water substantially raises the dissolved-solids content of Tonawanda Creek during periods of low flow (fig. F-3).

Much of the ground water in the area is hard to very hard, including the ground water high in sulfate and chloride. Water in the Onondaga Limestone and the Lockport Dolomite (fig. D-2) is particularly hard and is high in dissolved solids. This is reflected in the chemical quality of the small streams at low flow (fig. F-1). Water discharging from the Onondaga Limestone raises the hardness and dissolved solids content of Tonawanda Creek significantly (fig. F-3).

Dissolved gases also affect the usability of water from wells. In the northern half of the area, hydrogen sulfide gas is a common constituent of ground water. Its occurrence is widespread, but quite variable from one place to another. The gas has an obnoxious odor and is corrosive to plumbing.

Odorless but flammable gas (mainly methane) occurs in water obtained from the deeper ground-water reservoirs in valleys in the southern half of the area. A mixture of this gas and air is explosive upon ignition, and therefore some hazard exists in using ground water containing such gas. However, it is easily removed from the water by aeration.

Pollution

Buffalo River, the downstream reach of Smoke Creek, and Cattaraugus Creek downstream from Gowanda, are polluted by industrial wastes (fig. B-1). The principal objectionable constituents are phenols and chromium. Although these constituents may be present in only small amounts, even small amounts make the water unsuitable for many uses. Domestic and other organic wastes also pollute the reaches of the streams named above as well as some other streams.

The Buffalo River presents particular problems from a pollution standpoint because of the large discharges of chemical wastes it receives. During periods of low flow the concentrations of pollutants build up in the slow-moving water. During floods, these wastes are washed into Lake Erie where they sometimes kill large numbers of fish and enter public water-supply intakes. However, this pollution problem is being alleviated. (See sheet C, par. 6.)

Bacteria, detergents, nitrite, and nitrate from wastes contaminate ground water in the vicinity of any septic tank or cesspool. Densely populated areas where wastes are disposed of in septic tanks and where shallow ground water is therefore potentially polluted are shown on figure B-1. In parts of the area where soils are impermeable or poorly drained, particularly in the northern part, domestic wastes are discharged to drainage ditches or streams.

Deficient Municipal Supplies

Some public water-supply systems produce quantities of water reportedly insufficient or only barely sufficient for peak demands during hot, dry summer weather. These systems use sources that are either inadequate or inadequately developed at present, with the result that some of these systems have occasional water shortages or restrict the use of water. Figure B-1 shows the areas served by these inadequate public water-supply systems, based on information obtained as of June 1963, from the managers of the water systems.

Batavia and Arcade developed additional supplies in the latter part of 1963. Batavia formerly depended solely on Tonawanda Creek for its water supply, but the flow of the creek occasionally fell below the required amount. Wells were drilled to supplement the available supply from the creek. At Arcade the ground-water reservoir tapped by wells was further developed by drilling an additional well.

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SHEET C– FAVORABLE FEATURES OF THE AREA

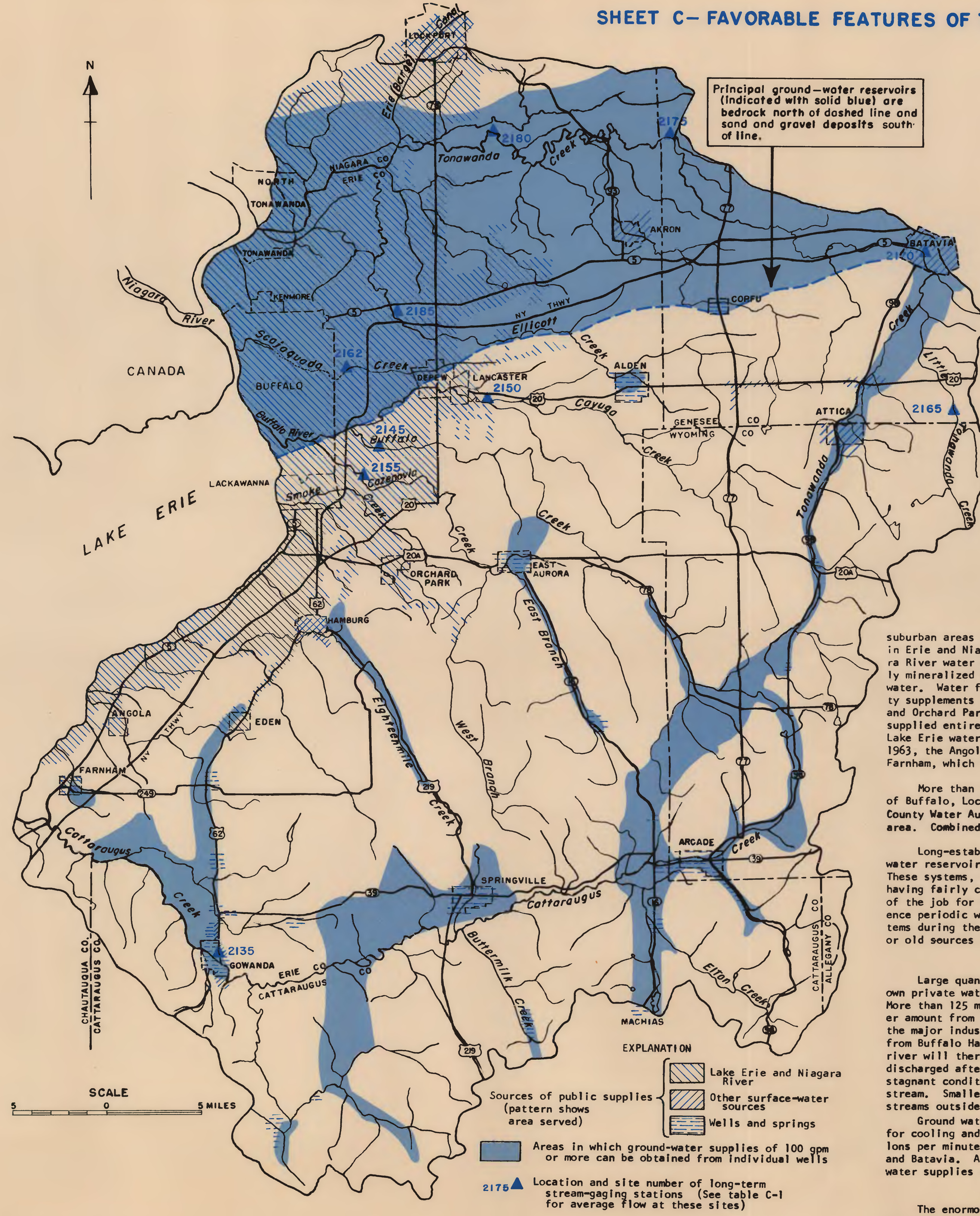


Figure C-1.--Areas presently served by public water supplies, and areas in which moderate or large ground-water supplies can be developed.

MAJOR WATER FACILITIES AND LARGE SUPPLIES

The present and potential water assets of the Lake Erie-Niagara area far outweigh its liabilities, or "water problems." The problems can be solved most effectively when the occurrence and interrelationships of water from all sources have been adequately defined.

The present water-supply facilities are mainly municipal and industrial water systems, and these are the water assets which are relatively well known. The locations of sources of additional supplies have been only partly defined. However, the total water resources are known to be large, as estimated from long-term data available for sites on some of the larger streams.

The average combined yield of all streams in the Lake Erie-Niagara area, other than Lake Erie and the Niagara River itself, is probably about 1,700 mgd (million gallons per day) or 2,700 cfs (cubic feet per second). Of this region-wide total, probably no more than 200 or 300 mgd is used at present, and a large part of this usage will be discontinued soon when the bulk of the industrial cooling water now withdrawn from the Buffalo River is replaced by a system using Lake Erie as its source. Furthermore, the 200-300 mgd totals cited above include what is probably a substantial re-use of the same water in some of the more heavily industrialized areas. Therefore, the total region-wide withdrawal which is never returned to a usable source is possibly very small, perhaps no more than 30 mgd. Thus, the Lake Erie-Niagara area has available to it a tremendous quantity of water for development, even exclusive of Lake Erie.

Public Water Supplies

Public water supplies are provided from Lake Erie and the Niagara River, from streams tributary to the lake or the river, and from ground-water sources. The area served from Lake Erie and the Niagara River includes the most industrialized and densely populated communities. In much of this service area, streams and ground-water reservoirs offer limited supplies or water of poor quality. Pipelines carrying Lake Erie water have been extended into rural and suburban areas in recent years. In the parts of Tonawanda Creek basin in Erie and Niagara Counties, areas now served with Lake Erie or Niagara River water were formerly dependent on private wells yielding highly mineralized water, on cisterns storing rainwater, or on trucked-in water. Water from Lake Erie supplied by the Erie County Water Authority supplements locally developed supplies of the villages of Hamburg and Orchard Park. Eden, which formerly was supplied from wells, is now supplied entirely by the Water Authority. Farnham is supplied with Lake Erie water from the Angola municipal system, but during part of 1963, the Angola system could not produce sufficient water to supply Farnham, which then reverted temporarily to using its ground-water system.

More than one million people are served by the municipal systems of Buffalo, Lockport, the Tonawandas, and the Erie County and Niagara County Water Authorities, which are the largest public supplies in the area. Combined average use from these systems is about 200 mgd.

Long-established water systems using either surface or ground-water reservoirs as sources serve communities inland from Lake Erie. These systems, in general, were designed to serve specific small areas having fairly constant numbers of people. The systems still do most of the job for which they were intended, although some systems experience periodic water shortages. Increased demand on most of these systems during the past 10 years has caused new sources to be developed or old sources to be improved.

Industrial Water Supplies

Large quantities of water are used by industries maintaining their own private water systems, principally for cooling and processing. More than 125 mgd is pumped from the Buffalo River and a somewhat larger amount from Lake Erie. A project now under development will supply the major industries along the Buffalo River with water for cooling from Buffalo Harbor at a rate of more than 100 mgd. Pumpage from the river will therefore be greatly reduced. The cooling water will be discharged after use to the Buffalo River and will help alleviate the stagnant conditions and the buildup of pollutants now present in the stream. Smaller amounts of water are used by industries located on streams outside the Buffalo metropolitan area.

Ground water from wells is also used by a number of industries for cooling and process water. Supplies of as much as 1,200 gpm (gallons per minute) are obtained from individual wells in the Tonawandas and Batavia. At many other locations, industries have developed ground-water supplies of a few hundred gallons per minute.

DEVELOPING ADDITIONAL WATER SUPPLIES

The enormous quantity of water available from Lake Erie overshadows the water available from the many relatively small drainage basins of the area. Nevertheless, the water available in the streams and ground-water reservoirs of the area is large and greatly exceeds the

Table C-1.--Average flow at long-term stream-gaging stations

Site number	Stream and location	Drainage area (sq mi)	Average flow (cfs)	Average flow (mgd)
2135	Cattaraugus Creek at Gowanda	428	717	464
2145	Buffalo Creek at Gardenville	145	190	123
2150	Cayuga Creek near Lancaster	93.3	125	80.8
2155	Cazenovia Creek at Ebenezer	136	218	141
2162	Scajaquada Creek at Buffalo	15.7	27.7	17.9
2165	Little Tonawanda Creek at Linden	22.0	27.4	17.7
2170	Tonawanda Creek at Batavia	172	200	129
2175	Tonawanda Creek near Alabama	230	272	176
2180	Tonawanda Creek at Rapids	358	392	253
2185	Ellicott Creek at Williamsville	76.3	90.6	58.6

present withdrawal from these sources.

The average streamflow indicated in table C-1 above is the volume of water available on a long-term basis from the principal streams at the points indicated. Utilization of most of the average annual streamflow, if demands were relatively constant, could be achieved only by the construction of reservoirs. Without reservoirs, perennially dependable supplies would be limited to rates of use lower than the average streamflow. However, even reservoir construction has hydrologic as well as economic limits on its value, especially in areas of relatively low relief, such as characterizes the lowland part of the Lake Erie-Niagara area. Under these conditions the area of the water surface of a reservoir is large in comparison to the depth and volume of the reservoir. Therefore, large quantities of water in the reservoir would be lost each year by evaporation.

Large quantities of water could be stored in the eastern, central, and southern parts of the area if reservoirs were built on streams in that region. Rainfall and streamflow are highest in the uplands (fig. E-1) and the quality of the water is relatively good (fig. F-1). The Cattaraugus Creek basin has the largest streamflow in the area and, upstream from Gowanda, contains the best quality of water. Upstream from Elton Creek, and most tributaries upstream from Buttermilk Creek, contain particularly good quality water. Reservoirs large enough to store overland flow would contain water comparable in quality to that from Lake Erie.

Reservoirs might also be useful for one or more of the purposes of water supply, flood control, and recreation in the Buffalo, Cayuga, and Cazenovia Creek basins. Small releases from the reservoirs during periods of low flow would increase flow through the middle and lower reaches of the streams and improve the chemical quality of the water in the streams. Storing water and controlling the release during the winter, might cut down ice buildup in middle reaches of the streams and reduce the danger of flooding caused by ice jams during brief mid-winter thaws or in early spring.

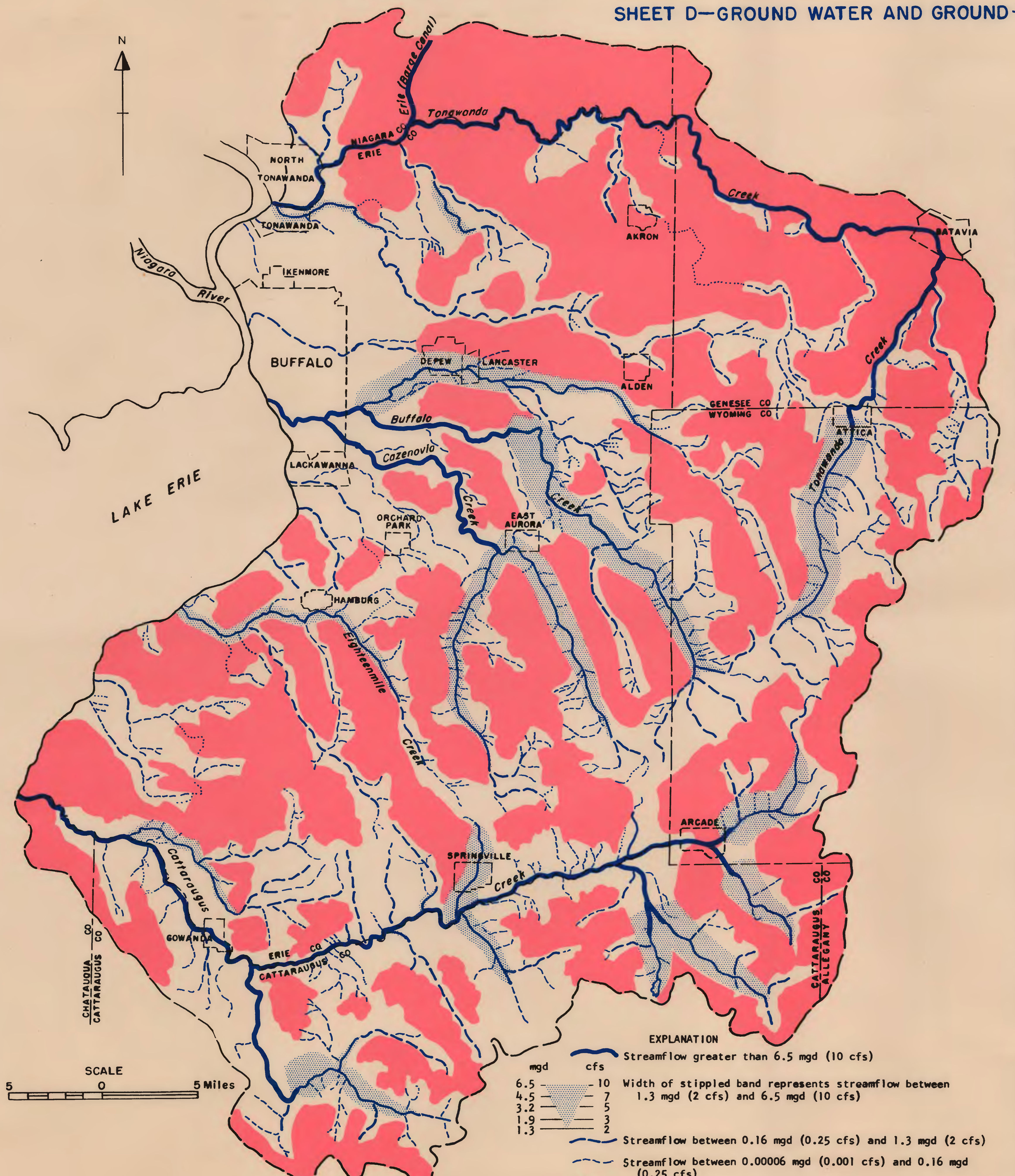
Areas where ground-water supplies of 100 gpm or more can be developed from individual wells are shown on figure C-1. Thick and permeable sand and gravel deposits that lie in the stream valleys are the most favorable deposits for obtaining large supplies of ground water. At some locations, wells yielding 1,000 gpm or more can be developed in these deposits. The water yielded by the sand and gravel is generally of good quality, though somewhat hard. In some places, the water would require softening and possibly iron removal, if it were to be used for public supply.

A broad belt of rocks, generally limestone, dolomite, and shale containing gypsum and salt, extending eastward from Buffalo and the Niagara River also will produce yields of 100 gpm or more from individual wells. Near the Niagara River the rocks of this belt will yield as much as 1,200 gpm. The water is highly mineralized and therefore its use is largely limited to cooling water for industry.

WATER RESOURCES OF THE LAKE ERIE–NIAGARA AREA

A PRELIMINARY APPRAISAL

SHEET D—GROUND WATER AND GROUND-WATER DISCHARGE



EXPLANATION

Streamflow greater than 6.5 mgd (10 cfs)

mgd	cfs
6.5	10
4.5	7
3.2	5
1.9	3
1.3	2

Width of stippled band represents streamflow between 1.3 mgd (2 cfs) and 6.5 mgd (10 cfs)

Streamflow between 0.16 mgd (0.25 cfs) and 1.3 mgd (2 cfs)

Streamflow between 0.00006 mgd (0.001 cfs) and 0.16 mgd (0.25 cfs)

No measurable streamflow in red areas

No measurable streamflow; selected channels shown only for continuity or clarity

Figure D-1.--Discharge of streams at 90-percent duration point, based on measurements made in July 1963, when flow of most streams was supplied entirely by ground-water inflow.

OCCURRENCE AND USE OF GROUND WATER

Ground water, that water available from wells and springs, is still a relatively undeveloped resource in most of the Lake Erie-Niagara area. Although many of the smaller public water-supply systems depend upon water from wells and springs (sheet C, fig. C-1), the total municipal use of ground water probably averages about 3 mgd (million gallons per day), and the total ground water used for all purposes, including agricultural and industrial supplies, is probably between 10 and 15 mgd. The total unused ground-water reserves appear adequate to sustain an average use many times the present rate of use.

The natural environment of ground water is the complex interconnected network of pore spaces and fractures in rocks at various depths below the land surface. The availability of ground water thus was assessed on the basis of data on wells, geology, and the discharge of ground water to streams. The well data show that the largest supplies of ground water -- as much as 1,200 gpm (gallons per minute) from individual wells -- are obtained from sand and gravel deposits located mainly in valleys and from bedrock in a belt across the northern part of the area. The distribution of these rocks and deposits defines the areas favorable for developing wells of high yield as shown in figure C-1.

The discharge of ground water to streams was studied intensively throughout the project area during a short period in July 1963, when streamflow of the smaller streams and tributaries was small and was due entirely or almost entirely to ground-water discharge. The data obtained were the principal source of information for figure D-1, which shows the magnitude of streamflow at the 90-percent duration point; that is, streamflow that is equaled or exceeded 90 percent of the time. Ground-water discharge, as indicated by low streamflows, is an approximate measure of the quantity of water available for development without permanently depleting the amount of water stored in the ground. Large gains in streamflow within short distances indicate ground-water discharge from permeable materials. Low or non-existent inflow of ground water indicates relatively impermeable materials.

GROUND WATER POTENTIAL

The availability of ground water to individual wells depends on the permeability and thickness of the ground-water reservoirs. A thick and permeable ground-water reservoir will yield large supplies of ground water. The amount of water that will move through a ground-water reservoir is dependent on the coefficient of transmissibility. This is defined as the volume of water in gallons per day that will pass through a one-foot wide vertical strip of the reservoir under a hydraulic gradient of 1 foot per foot. It is equal to the saturated thickness multiplied by the permeability of the reservoir. The coefficient of transmissibility (hereafter called simply transmissibility) is a convenient measure of comparison of ground-water reservoirs of differing permeability and thickness.

Large Supplies from Sand and Gravel Deposits

Sand and gravel deposits consist of sorted and stratified sand interbedded with gravel composed of granules, pebbles, and cobbles. The more permeable deposits contain little silt or fine sand to fill in the spaces separating the larger grains. Large pore spaces, particularly in beds of granules and pebbles, make a deposit very permeable. Individual wells in some sand and gravel deposits yield more than 1,000 gpm. However, yields from most sand and gravel deposits are considerable less. In many deposits, yields of wells do not exceed 500 gpm, and in some relatively thin deposits, yields are less than 100 gpm.

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The most productive deposits of sand and gravel lie in valleys in, or that emerge from the Appalachian Uplands. Other productive deposits lie on the Lake Erie plain northwest of Gowanda. The extent of the sand and gravel deposits that will provide large yields to wells is indicated in figure C-1, south of a line between Buffalo and Batavia.

Large municipal or industrial ground-water supplies are presently obtained from sand and gravel deposits at Batavia, East Aurora, Arcade, Springville, and Gowanda.

The deposits at and south of Batavia are part of a ground-water reservoir that occupies the valley of Tonawanda Creek (fig. C-1). In the vicinity of Batavia, wells yield as much as 1,200 gpm. The deposits there have a moderate saturated thickness, generally 50 to 70 feet, but are very permeable. Specific capacities of the wells in the deposits near Batavia range from 35 to 100 gpm/ft (gallons per minute per foot of drawdown) and transmissibilities from 40,000 to about 100,000 gpd/ft (gallons per day per foot of width of water-bearing formation) or more. The ground-water discharge to Tonawanda Creek upstream from Batavia exceeds 8 mgd. Of this quantity, at least 2 mgd is discharged to Tonawanda Creek in the extensive part of the ground-water reservoir from the Genesee County line north to Batavia. About 1 mgd is pumped from the deposits near Batavia and is discharged to Tonawanda Creek north of the ground-water reservoir

The ground-water reservoir at East Aurora, and partly in the valley of Buffalo Creek, is of small extent (fig. C-1). It is more than 130 feet thick, but is only moderately permeable. Individual wells yield as much as 700 gpm, but specific capacities are only about 8 to 15 gpm/ft. Transmissibilities of the deposits are about 10,000 to 17,000 gpd/ft. Because of the moderate thickness of the deposits, a large drawdown is available, so that large yields can be obtained even though the transmissibility of the deposits is not exceptionally high. The natural discharge from the ground-water reservoir to two small tributaries of Buffalo Creek is about 0.8 mgd when the streams are at the 90-percent duration point. About 0.75 mgd is pumped from this ground-water reservoir and is discharged to East Branch Cazenovia Creek.

The sand and gravel deposits at Arcade are part of an extensive system of ground-water reservoirs that extend through the headwaters of Cattaraugus Creek to the headwaters of Tonawanda and Buffalo Creeks (fig. C-1). The deposits at Arcade are of unknown thickness but locally have a transmissibility of 60,000 gpd/ft and will provide yields of 300 gpm or more. The deposits have a much lower transmissibility in the valley to the southeast of Arcade.

Large areas of sand and gravel deposits in the north-trending and south-trending valleys west of Arcade have a very large potential for development. The deposits have not been adequately tested, but should yield supplies of a few hundred gallons per minute or more to individual wells. The ground-water discharge from these deposits is large. Hosmer Brook at Sardinia (3 miles west of Arcade) receives a ground-water inflow of 2 mgd in the lower mile of its course, when the streamflow is at the 90-percent duration point (fig. D-1).

The sand and gravel deposits at Springville are a few hundred feet thick. Wells in these deposits yield as much as 800 gpm and have specific capacities of 25 to 40 gpm/ft. Transmissiblities of the deposits range from 30,000 to 50,000 gpd/ft Discharge from the deposits to streams exceeds 5 mgd (fig. D-1).

At Gowanda, intensive use is made of a sand and gravel deposit about 45 feet thick, which is covered by more than 300 feet of relatively impermeable fine-grained sediments. Transmissibility of the ground-water reservoir is about 10,000 gpd/ft. Water levels in the wells have declined about 150 to 160 feet since 1929, and the yields of individual wells have declined as much as 50 percent. Similar concealed ground-water reservoirs lie in other parts of the Cattaraugus basin and in Eighteenmile, Cazenovia, and Buffalo Creek valleys (fig. C-1). The sustained yields of these buried sand and gravel deposits are low because of low rates of recharge through the overlying, poorly permeable deposits. Development of such ground-water reservoirs should proceed carefully, because early success may encourage overdevelopment.

Recharge of sand and gravel deposits can be obtained by induced infiltration, where the deposits are hydraulically connected to streams. By lowering the water level in the deposits by pumping and thereby causing the ground-water gradient to slope away from the stream, water can be induced to move into the ground from the stream toward the pumping wells. Very large quantities of water thus can be pumped from permeable deposits that lie along streams, because the amount of water that can be pumped is not limited to the recharge obtained by infiltration into the ground of local precipitation. In fact, ground-water reservoirs situated in valleys function hydraulically much like surface-water reservoirs to the extent that water is removed from storage when withdrawals exceed replenishment and storage is replaced during floods and other times of excessive streamflow.

Figure D-2.--Generalized bedrock geologic map of the Lake Erie-Niagara area.

Large Supplies from Bedrock

Rocks that will yield large supplies of ground water underlie a belt across the northern part of the area from Buffalo to Batavia. The principal rock units in this belt are the Lockport Dolomite, which forms a strip along the north-central part of the belt; the Salina Group, which underlies most of the belt; and the Onondaga Limestone, which forms a continuous strip along the south edge of the belt. (See fig. D-2.) The rocks are layered and dip southward. The Lockport Dolomite, of Middle Silurian age, comprises the oldest rocks.

The Lockport Dolomite is composed of dolomite and dolomitic limestone. The Salina Group consists mainly of shale, but contains layers of gypsum and salt. The Onondaga Limestone is composed mainly of limestone, which in some places contains chert.

These bedrock units transmit water through fractures and openings between beds. Water-bearing properties of the rocks are variable and depend on the degree of fracturing and the extent to which the fractures have been enlarged by solution of the rocks. Transmissibility of the Onondaga Limestone ranges from about 5,000 to 10,000 gpd/ft, and wells in the group yield as much as 100 gpm with specific capacities of 4 to 8 gpm/ft. The Lockport Dolomite probably has comparable water-bearing properties, though yield information has not yet been obtained on the Lockport where it lies within this area.

The water-bearing openings in the Salina Group have been considerably increased in size by leaching of gypsum and salt contained in the shale. As a result, the Salina is very permeable and provides yields of as much as 1,200 gpm. The transmissibility exceeds 100,000 gpd/ft at some places, but probably is considerably less in most other places. The gain in streamflow of Tonawanda Creek where it crosses the Salina Group is about 0.2 mgd per mile of stream length when the stream is at the 90-percent duration point.

"Low Yielding" Ground-Water Areas

More than half the Lake Erie-Niagara area is underlain by rocks and glacial deposits that will yield only small supplies of water -- generally less than 10 to 20 gpm. These areas are underlain by shales and sandstones that are covered with till or fine-grained sediments.

The bedrock of small ground-water potential consists mainly of shale with interbedded fine-grained sandstone. These rocks lie south of the Onondaga Limestone and underlie the Appalachian Uplands and the Lake Erie plain south of Buffalo.

Clay, silt, and fine sand in horizontal beds comprise fine-grained sediments that underlie extensive parts of the Erie-Ontario Lowlands and some of the valleys in the Appalachian Uplands. The fine-grained sediments will yield only small supplies of water to wells. Where composed predominantly of clay they are essentially impermeable.

Till is an unsorted mixture of rock fragments of all sizes. In the Lake Erie-Niagara area it is mainly either silty or clayey and contains only scattered stones. However, some of the till in the southern half of the area is very stony. Because till contains a large percentage of silt and clay and is unsorted, the pore spaces are small and the permeability is low. Till yields a few hundred gallons per day, at most, to individual wells.

Ground-water discharge is small from these "poor" ground-water areas. The low permeability of the rocks and deposits allows only comparatively small amounts of water to infiltrate the ground. The rocks and deposits do not store sufficient ground water to sustain the flow of streams draining them. During the summer and early fall the streams either dry up or are reduced to very low flows. (See fig. D-1.)

WATER RESOURCES OF THE LAKE ERIE-NIAGARA AREA
A PRELIMINARY APPRAISAL

SHEET E-STREAMFLOW

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY — WATER RESOURCES DIVISION
NEW YORK STATE WATER RESOURCES COMMISSION
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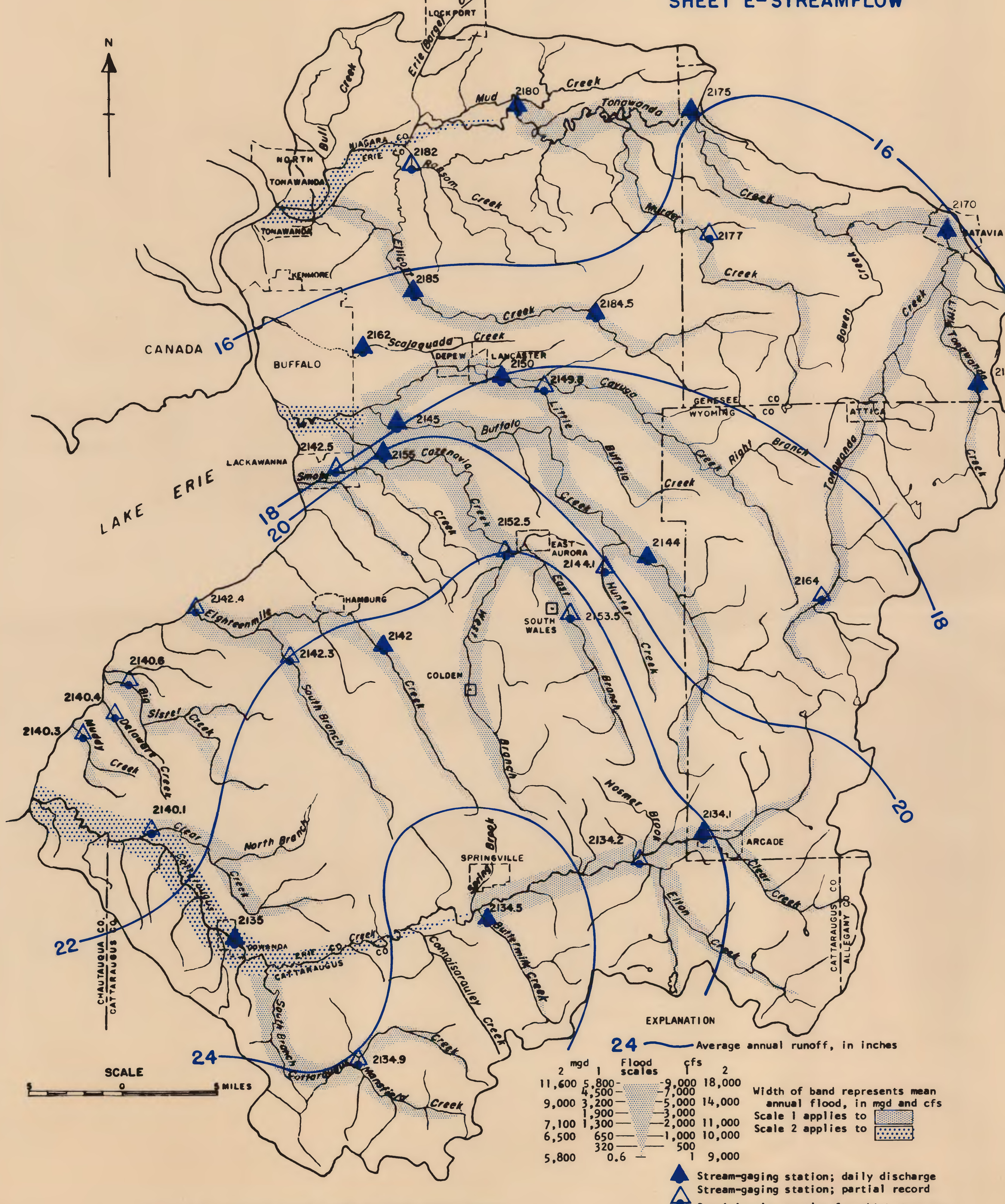

Figure E-1.--Average annual runoff and mean annual floods.

THE STREAM SYSTEMS

The three principal stream systems in the Lake Erie-Niagara area are Cattaraugus Creek, Buffalo River, and Tonawanda Creek, with a combined drainage area of approximately 1,660 square miles. These systems have a combined average yield of about 1,500 mgd (million gallons per day) or 2,300 cfs (cubic feet per second) estimated primarily on the basis of more than 20 years of continuous measurements by the Geological Survey at stream-gaging sites having a combined drainage of about 1,240 square miles. The average flow at these and several other sites is given on table C-1, sheet C.

There are some 270 square miles of small drainage basins not a part of the three principal stream systems. The average flow of these smaller streams is still being investigated. However, the combined average flow may be about 250 mgd (380 cfs).

VARIABILITY OF STREAMFLOW

In contrast to average conditions, streamflow may vary widely both seasonally and on a particular day. For example, during much of the period from July through October 1963, the combined daily stream discharge from the entire region fell below 190 mgd (300 cfs). Within this same period, however, a record flood occurred on Scajaquada Creek as a result of the second of three intensive summer storms within a two-week period in the immediate Buffalo area. All area streams experienced above average runoff at about the same time, but while Scajaquada Creek was at flood water levels, stream levels in the adjacent basins -- Cayuga and Ellicott Creeks -- rose only moderately.

When considered in terms of region-wide averages, a large supply of surface water is available (in addition to the tremendous supplies in Lake Erie and the Niagara River), but when considered in the way the resource actually occurs, the supply is subject to large variations in time and place. The present study has made a start toward determining the frequency and magnitude of low and high streamflow throughout the area.

PRECIPITATION AND RUNOFF

Precipitation is the source of stream runoff. The water takes either or both of two routes toward stream channels. One route is over the land surface and the other route is into the ground moving downward to the zone of saturation (ground water). During and immediately after a rainfall, overland flow is substantial, comprising a major portion of streamflow. During dry-weather periods there is no overland flow. Stream runoff is then comprised of ground-water discharge into the streams through their beds and banks. Which route is followed, and to what extent, is largely determined by precipitation intensity, although many other factors also play an important part. The greater the intensity of precipitation, the greater the proportion of overland flow.

Average annual precipitation in the region ranges from 31 inches in the north to 44 inches in the south (sheet A, fig. A-1). Average annual runoff, as shown on adjacent figure E-1, is between about 15 inches (0.7 mgd per square mile or 1.1 cfs per square mile) in the north and about 25 inches (1.2 mgd per square mile or 1.8 cfs per square mile) in the south. Thus, both precipitation and stream runoff are higher in the Appalachian Uplands than on the Erie-Ontario Lowlands. Obviously, a large portion of precipitation does not appear as stream runoff. This is water returned to the atmosphere by evaporation and transpiration (use of water by vegetation). This evapotranspiration loss is slightly higher in the uplands than the lowlands, by about two or three inches per year. This may be an example of the principle that in a single climatic region the larger the total precipitation (and therefore water available for evapotranspiration), the larger will be the loss of water by evapotranspiration (Thornthwaite, 1948).

Here again we have been dealing with long-term averages, but the differences between precipitation and runoff are more readily understood when considered season by season. Precipitation during each season tends to be about the same, from 8 to 11 inches during each 3-month period. However, stream runoff is markedly high in early spring and quite low in midsummer. (See fig. E-2; and sheet A, fig. A-2.) The high stream runoff is a result of spring rains combined with snowmelt. This causes both high overland flow and high ground-water discharge. Water loss by evaporation and transpiration is at a minimum. During the summer growing season the reverse situation prevails. Temperatures and rates of evapotranspiration are high, and no overland flow occurs except during storms. Ground-water recharge and discharge are low. Stream runoff, therefore, is at a minimum.

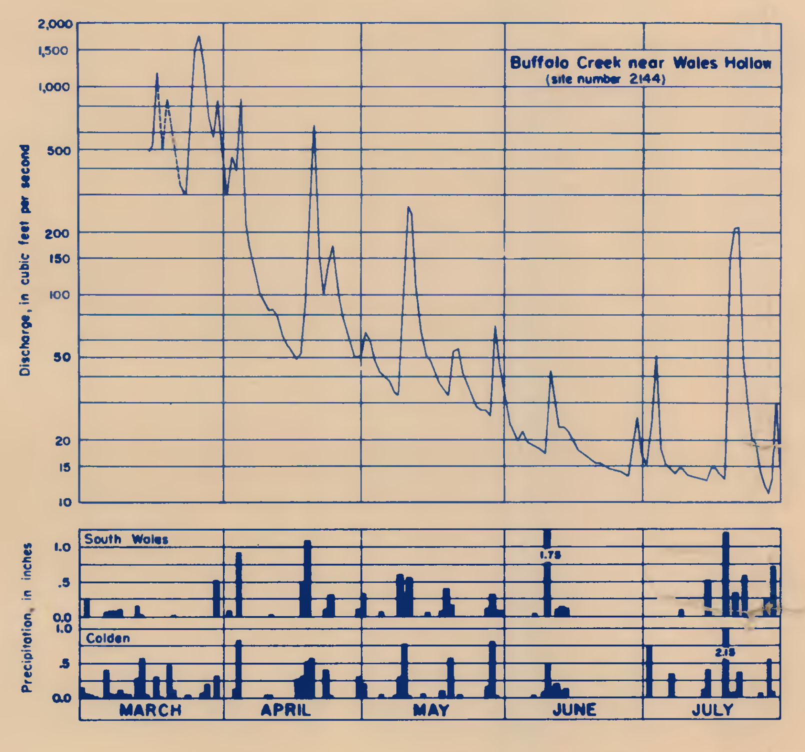

Figure E-2.--Daily discharge of Buffalo Creek near Wales Hollow (site number 2144) and precipitation at South Wales and Colden during the spring and summer of 1963.

FLOODS

Most peak streamflows which cause floods occur during March and April, because of the weather and stream runoff characteristics described above. Floods caused by ice jams, however, may occur not only in early spring, but also in mid-winter. Temperatures 15° to 25° F above freezing, accompanied by rain, are sufficient to melt some of the snow cover, producing direct runoff and breaking up the ice cover in the streams. Although these conditions causing ice-jam floods have never produced the maximum recorded streamflows, the most extensive and damaging flood inundation in the Lake Erie-Niagara area often results from ice-jam floods.

The most recent ice-jam flood occurred in March 1963, at the mouth of Cattaraugus Creek. One of the largest ice-jam floods occurred in March 1942, on the several tributaries of the Buffalo River. Figure B-1, sheet B, shows the principal areas subject to flood inundation in recent years.

Damaging floods which affect large sections of the region and are caused by rainfall alone are relatively unusual. The areal pattern of such floods is more likely to be of a local nature, such as was true in the August 7, 1963, flood of Scajaquada Creek. The flood of June 1937, largest in the region during the past 26 years, was essentially confined to the Buffalo River basin. Estimates of peak discharge during that flood, by the Corps of Engineers, include 22,000 cfs (152 cfs per square mile) for Buffalo Creek at Gardenville (site 2145), and 18,000 cfs (193 cfs per square mile) for Cayuga Creek near Lancaster (site 2150).

Peak discharge and total flood volume are significantly lower for the streams in the northern third of the area. Low stream gradients dampen the downstream movement of flood peaks. Also, there is somewhat less precipitation in the north, and therefore lesser flood volumes.

Mean Annual Flood

Knowledge of the magnitude and frequency of flood streamflows is one of the main prerequisites to the most efficient location and design of flood-control structures and the effective establishment of flood-zoning practices. Plans for dams, levees, and bridges, and flood-plain development all require flood-frequency analyses. A Statewide study of this subject has been made by the U.S. Geological Survey (Robison, 1961). The result is a graphic procedure for determining flood magnitude with occurrence frequencies between once in 1.1 years and once in 50 years. The mean annual flood flows, shown by width of open band on figure E-1, were prepared from this study. (By definition, an "annual flood" is the largest instantaneous discharge occurring in a given year, and the "mean annual flood" is that peak discharge which is equaled or exceeded, on the average, once every 2.33 years.)

The magnitude of peak flood flow which will be likely to recur at lesser or greater intervals may be determined by multiplying the mean annual flood values on figure E-1 by the appropriate ratios selected from figure E-3. The flood-frequency analysis noted above does not apply to drainage areas of less than 10 square miles, nor to ice-jam floods, a phenomenon not generally adaptable to significant analysis by present flood-frequency statistical methods.

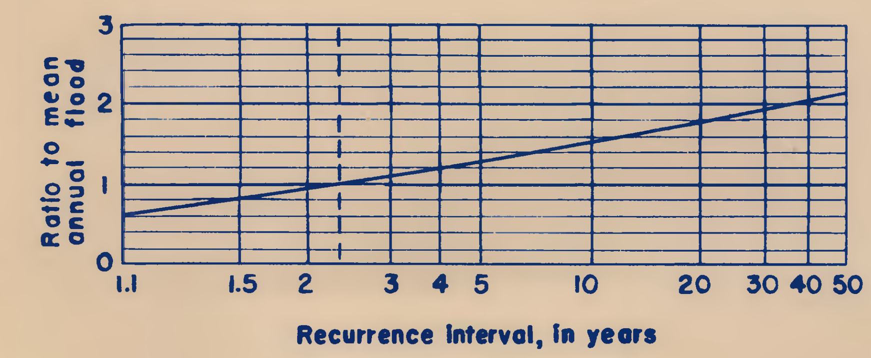

Figure E-3.--Graph for use with figure E-1 in order to determine frequency of floods of various magnitudes in the Lake Erie-Niagara area (not applicable to floods caused by ice jams).

Flood Routing

Flood routing is another factor of importance in determining the nature or feasibility of flood-control structures. For this analysis a "flood" is defined as the maximum concentration of water resulting from a storm event. "Routing" has been areally generalized and expressed as velocity in miles per hour. Within any one drainage basin, the time required for concentration of overland flow and downstream passage of one or more flood waves is subject to variation from place to place within the basin. There is also variation from basin to basin. In both situations, the variations occur because of local differences in topography, physiography, and geology.

Successful analysis of this element of water movement is dependent on the number and location of sites where the time of concentration of overland flow and the time of passage of flood waves can be determined. Precipitation duration and magnitude must also be available. A preliminary analysis for this report included a selection of spring and summer storms during 1963 which produced rainfall varying areally between 0.4 and 1.2 inches.

The analysis revealed most velocities in the region were between 0.5 and 2.5 miles per hour. The highest velocities were in the upper Tonawanda and Buffalo basins. The lowest velocities occurred in the lower Tonawanda basin west of Batavia and in the Cattaraugus basin east of Arcade. Most of the remainder of the region had velocities between 0.8 and 1.6 miles per hour for the storm events studied.

It should be noted that these velocities are conservative, reflecting retardation of overland flow by vegetation. In contrast, rainfall of the same magnitude after the end of the growing season will produce faster-moving overland flow.

LOW STREAM RUNOFF

Low stream runoff, consisting of ground-water discharge, is described on sheet D. Figure D-1 shows low streamflows expected only about 10 percent of the time. Three types of useful knowledge can be derived from further analysis of this information. These are:

1. Amount of water available for dilution of municipal and industrial wastes during extended dry periods.
2. The minimum amount of water available most (90 percent) of the time for present and potential water-supply developments without storage facilities.
3. Indication of approximate areas where moderate or large ground-water supplies are readily obtainable. (See also fig. C-1.)

The water manager seeking to develop additional supplies from streams should recognize that even lower flows than those shown on figure D-1 will sometimes occur. How much less these lower flows will be and how often they are likely to recur is controlled by the geologic environments within the region. Further flow-duration analysis is necessary to provide such data as the minimum consecutive, seven-day streamflow which will occur once in a ten-year period.

The rate of depletion during dry-weather periods, indicated by the long-term gaging network, is similar from basin to basin throughout the region. This means, for example, that in late summer, all streams will reach the 90 percent duration point of flow at approximately the same time.

The present magnitude of water use on the Lake Erie plains obscures the natural ground-water discharge characteristics of that part of the region. For example, a number of smaller streams on the periphery of Buffalo are utilized for the discharge of municipal and industrial wastes. Further south there is extensive irrigation using water from both surface and ground sources. A significantly large portion of this water is lost through evapotranspiration.

During extended dry-weather periods, the pattern of perennial streamflow varies widely within the region. The tributary channels in the middle and lower Tonawanda basin, shallowly incised in clay and till, dry up relatively quickly. However, the channel of Tonawanda Creek itself has probably been incised onto or close to the porous Salina Group and therefore receives relatively large amounts of ground-water discharge.

A narrow belt of deposits in the transitional area from the lowlands to the uplands, which is generally of low permeability, provides perennial but small ground-water discharge in that part of the region.

Within the uplands, particularly in the Cattaraugus basin, perennial ground-water discharge is of relatively large magnitude. Steep basin gradients combined with thick, permeable stratified deposits induce considerable ground-water discharge.

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Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: The Geographical Review, vol. 38, p. 55-94.

WATER RESOURCES OF THE LAKE ERIE-NIAGARA AREA

A PRELIMINARY APPRAISAL

SHEET F — CHEMICAL QUALITY OF WATER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY — WATER RESOURCES DIVISION
NEW YORK STATE WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

SIGNIFICANT AREAL VARIATIONS

Chemical quality characteristics of ground and surface waters in the Lake Erie-Niagara area vary widely from one place to another. However, most of the available water resources may be used for many purposes with some water treatment, such as softening or reduction of iron content. On the other hand, in some northern parts of the region the concentrations of chloride or sulfate are so high that water treatment for some uses would be impractical or uneconomical.

The "best" waters, that is, those which contain the lowest concentrations of dissolved solids and no constituents above objectional limits for most uses, are those in unpolluted parts of Lake Erie and in streams and ground-water reservoirs in the Appalachian Uplands. The stream waters commonly contain no more than 200 or 300 ppm (parts per million) of dissolved solids, and sometimes only about 100 ppm. Ground water in the southern part of the uplands generally ranges from 200 to 300 ppm in dissolved solids. In contrast to these relatively low concentrations, some small streams in the northeastern part of the region, and wells in the same region, contain water with dissolved-solids concentrations higher than 600 ppm.

The chemical quality of water in a particular stream or well here, as elsewhere, is a combination of the effects of the two or three "environments" through which the water has moved -- the atmosphere (as rain or snow), the surface of the land (as overland flow and streamflow), and the geologic environment (as ground water). Some of the constituents most commonly dissolved in naturally occurring waters in these three environments include silica, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate.

CHEMICAL CONTENT OF PRECIPITATION

Rain and snow, as they fall, tend to "wash" the atmosphere of "impurities," such as dust particles, and in so doing dissolve small amounts of the impurities. Part of the dissolved solids are from smoke and gases rising from the industrial areas.

The dissolved-solids concentration of the 105 samples of rainfall collected at seven sites between March and September 1963 ranged from 10 to 170 ppm, and the median value was 35 ppm. The principal constituent was sulfate, averaging 15 ppm. Most precipitation samples contained little or no chloride. The dissolved-solids concentration was slightly higher in the Buffalo area than elsewhere.

CHEMICAL QUALITY OF WATER IN STREAMS

Water in streams contains not only the dissolved solids from precipitation, as noted above, but also additional quantities of solids dissolved from the surface of the land during overland flow and from the soil and rocks (beneath the land surface) through which ground water flows on its way to a stream. Streams generally contain the least concentrations of dissolved solids during high-streamflow periods when rates of overland flow and streamflow are highest, and the greatest concentrations during dry-weather low-streamflow periods when practically all the flow is from ground-water discharge.

The relatively low dissolved-solids concentration of water in some of the larger streams during high flows is shown by the upper numbers next to the triangles on figure F-1, the concentrations ranging from 94 to 176 ppm of dissolved solids. In these same samples sulfate ranged from 18 to 35 ppm, chloride from 5.0 to 16 ppm, and hardness from 56 to 124 ppm. These data are from samples collected between March 18 and 21, 1963. The dissolved-solids concentration of smaller streams would no doubt show a wider range of values, perhaps from 50 ppm (representing mainly the mineral content of the precipitation itself) to about 300 ppm (in streams draining the areas underlain by soluble rocks).

As streamflow declines, a greater proportion of the water in the stream is derived from the ground-water reservoirs. In table F-1, partial chemical analyses are given for both moderate streamflow (May 7, 8) and low streamflow (July 2, 5) at the same sites identified on figure F-1. At most of the sites, the dissolved-solids content increases significantly as streamflow decreases from moderate to low discharge. A comparison of the concentrations for moderate and low flows given in table F-1 with the concentrations at high flows given on figure F-1 shows the dilution effect from overland runoff in the streams at high flows.

When the streams are at low flow and the water is derived entirely or almost entirely from ground-water storage, the quality of the water in the streams represents an average quality of the ground water contributing to the flow. Thus, the quality of the water in small streams in the Lake Erie-Niagara area reflects the quality of shallow ground water shown on figure F-1 by patterns. The stream water at low flow ranges generally from 100 to 2,300 ppm in dissolved solids, 30 to 1,200 ppm in sulfate, 5 to 320 ppm in chloride, and 75 to 1,500 ppm in hardness. The higher concentrations are in the northern part of the area. The most mineralized water is in Ellicott Creek and its tributaries and northward flowing tributaries of Tonawanda Creek. These streams flow over the Salina Group of geologic formations which contribute very mineralized water to them.

The variation of chemical quality with water discharge of a stream at a point can be seen by the example shown in figure F-2. This is a graph of the daily mean water discharge and a once-daily specific conductance measurement for Buffalo Creek at Gardenville (site 2145) for the period October 1, 1961 to September 30, 1962. The specific conductance gives a rough measure of the dissolved-solids concentration, which for this stream is approximately 0.62 times the specific conductance. In order to show the generally inverse relationship between the water discharge and the specific conductance (and therefore, also the dissolved-solids concentration) more clearly, the water discharge is plotted as increasing in a downward direction instead of upward. The water discharge varies little throughout long periods of the year as does the specific conductance during these same periods (note October to November, May to September). During the remainder of the time the variation in both discharge and conductance is often quite sharp. The very sharp rises in the specific conductance during late December and January are probably not due to natural changes in the chemical quality but may be caused by local pollution, such as the flushing action of relatively slow snowmelts on salted streets and roads during periods of relatively low streamflow.

Variation in the chemical quality along a stream is especially significant when a stream channel crosses areas of different geologic environments and the streamflow is low and therefore primarily consisting of ground-water discharge. Data from Tonawanda Creek provide an example of such a variation in chemical quality (fig. F-3). From the most upstream sampling point to the most downstream point, the dissolved-solids concentration increases from 198 ppm to 650 ppm. From the headwaters to Batavia (site 2170) there is relatively little change in the chemical quality of the water. The chemical quality of this section of Tonawanda Creek is fairly typical of streams in the southern part of the project area. Between Batavia (site 2170) and Indian Falls (site 2174) the concentration of dissolved solids increases due to very hard water entering the stream from the Onondaga Limestone. From Indian Falls to Rapids (site 2180), the dissolved solids in the stream increases because of the inflow of water from the Salina Group that is very high in sulfate content. (See fig. F-1 for location of numbered sites noted above.)

Table F-1.--Chemical analyses of water in streams at moderate and low flows during 1963

Site number	Name of creek (At or near place listed)	Date of collection	Water discharge (cfs)	Concentration, in ppm: Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$	Dissolved solids at 180°C
2134.1	Cattaraugus (Arcade)	May 7	69	18	8.8	141	172
		July 2	30	18	9.7	138	170
2134.2	Elton (The Forks)	May 7	72	22	6.0	140	162
		July 5	35	25	5.6	139	168
2135	Cattaraugus (Gowanda)	May 7	370	46	23	168	233
		July 5	135	41	37	177	287
2142	Eighteenmile (North Boston)	May 7	34	40	14	122	169
		July 2	3.0	43	19	168	228
2144	Buffalo (Wales Hollow)	May 8	32	36	8.0	170	200
		July 2	7.0	41	10	190	226
2153.5	East Branch Cazenovia (South Wales)	May 8	29	34	11	121	154
		July 2	5.3	38	12	146	199
2155	Cazenovia (Ebenezer)	May 8	76	47	32	153	220
		July 2	10	69	48	190	296
2170	Tonawanda (Batavia)	May 8	73	38	13	204	238
		July 2	21	41	12	187	236
2175	Tonawanda (Alabama)	May 8	115	73	31	257	333
		July 2	35	84	46	282	410
2180	Tonawanda (Rapids)	May 8	109	134	31	321	437
		July 2	48	240	48	455	650
2184.5	Ellicott (Mill Grove)	May 8	10	49	32	230	302
		July 5	2.0	82	86	261	472
2185	Ellicott (Williamsville)	May 8	23	103	42	272	384
		July 2	.9	353	57	486	717

Figure F-1.--Dissolved-solids concentrations of shallow ground water, based on analyses of water in streams at low flow; and of water at selected stream sites at very high flow.

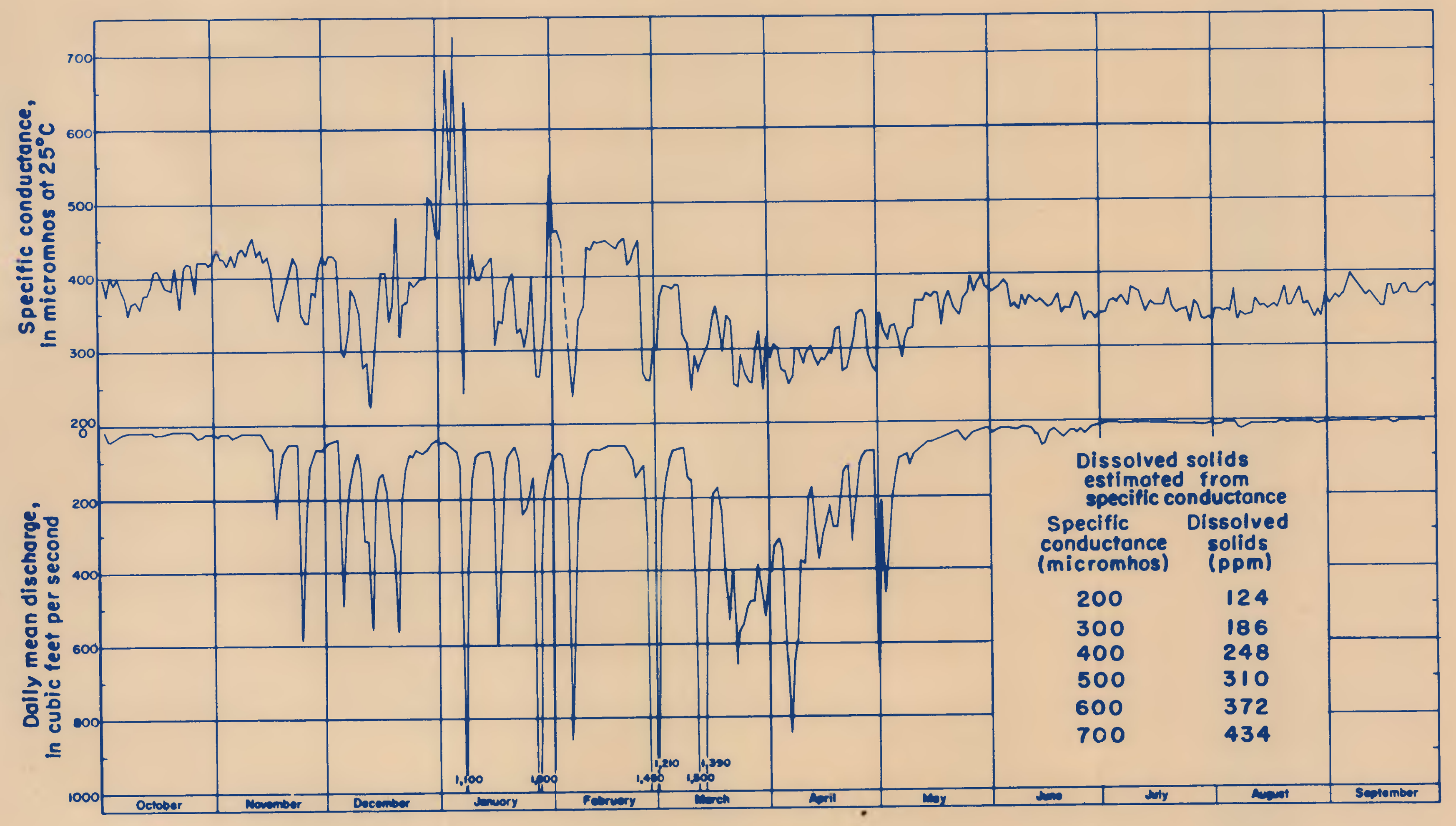

Figure F-2.--Daily discharge and specific conductance of Buffalo Creek at Gardenville, October 1961 to September 1962.

QUALITY OF GROUND WATER

The dissolved-solids content of ground water results largely from solution of soil and rock materials. The dissolved-solids content of ground water in the Lake Erie-Niagara area ranges from about 40 ppm to 7,000 ppm. An average of only about 35 ppm of these concentrations is contributed by precipitation; the remainder is dissolved as the water percolates through the ground. Variation in the composition and solubility of the rock materials and soil from place to place is the main cause of differences in the quality of the ground water. Its quality therefore, like that of surface water, varies geographically, but seasonal variation is usually minor. Analyses of samples of ground water from the area are summarized in table F-2.

The least mineralized ground water, and therefore that which is suitable for many uses with little or no treatment, is found in some of the more porous glacial deposits in the Appalachian Uplands in the southern part of the Lake Erie-Niagara area. (See fig. C-1 for approximate location of these deposits.) In the glacial deposits in the upper Cattaraugus Creek valley and the South Branch Cattaraugus Creek valley, the dissolved-solids content is generally less than 200 ppm. The regional location of ground water of relatively moderate or low mineral content is also reflected by the unpatterned part of figure F-1 identifying shallow ground water with dissolved-solids concentrations between 100 and 300 ppm. The "ground-water" data on figure F-1 are based mainly on analysis of samples of water in small streams during low flow conditions when all or almost all the water in the streams was derived from ground-water discharge into the streams.

The most highly mineralized water in the area is yielded by the Salina Group (fig. D-2). The sources of the dissolved solids are principally the gypsum and salt contained within the rocks. As a result the water is high in sulfate and sometimes chloride. Sulfate is generally in excess of 250 ppm and as high as 2,000 ppm. Chloride generally occurs in lower concentrations than sulfate and usually is less than 250 ppm. However, in most areas where dissolved solids are very high, chloride exceeds sulfate in concentration, and may be as much as 2,500 ppm. Hardness of the water from the Salina generally exceeds 1,000 ppm and ranges from 300 to almost 3,000 ppm. Hydrogen sulfide gas is a troublesome feature of the water from some parts of the Salina Group.

Table F-2.--Summary of chemical analyses of ground water in the Lake Erie-Niagara area

Water-bearing units	Number of samples collected	Sulfate (SO_4): Maximum (ppm)	Minimum (ppm)	Median (ppm)	Chloride (Cl): Maximum (ppm)	Minimum (ppm)	Median (ppm)	Hardness as $CaCO_3$: Maximum (ppm)	Minimum (ppm)	Median (ppm)	Specific conductance (micromhos at 25°C): Maximum	Minimum	Median
Salina Group	12	1,950	134	1,100	2,520	7.0	214	2,780	319	1,410	9,010	597	2,370
Glacial deposits overlying Salina Group	7	1,250	244	623	650	6.8	84	1,690	413	851	4,270	960	1,650
Lockport Dolomite and Onondaga Limestone	8	469	31	104	334	2.2	29	838	200	333	1,750	504	936
Sonyea and Genesee Formations	6	789	1.0	156	444	16	68	1,180	446	500	2,050	853	1,520
Middle and Upper Devonian shale and sandstone	37	164	.0	19	120	1.0	17	621	52	236	1,290	187	523
Glacial deposits overlying Middle and Upper Devonian shale and sandstone	64	179	.0	18	123	.8	10	412	22	158	1,120	66	392

The Lockport Dolomite and Onondaga Limestone (fig. D-2) yield water that is very hard and generally high in dissolved solids. The source of much of the dissolved solids is the carbonate minerals that predominate in the rocks. The hardness of the water from these rocks ranges generally from 200 to 800 ppm. The sulfate concentrations of water from the Lockport may be as much as 500 ppm owing to the presence of small bodies of gypsum in the rock. The sulfate and chloride concentrations of water from the Onondaga Limestone are high at some places, possibly due to the addition of water moving upward from the underlying Salina Group. Sulfate may be as much as 200 ppm and chloride as much as 350 ppm. Water in wells tapping the limestone or dolomite sometimes contains hydrogen sulfide.

The Middle and Upper Devonian shale and interbedded sandstone that underlie the southern half of the project area contain water whose chemical quality is largely determined by soluble carbonate minerals that are a minor constituent of the rocks. The water, except from a few wells, is very hard, in places exceeding 600 ppm in hardness. Sulfate and chloride concentrations are low, except at a few places where they exceed 100 ppm. These higher sulfate and chloride concentrations may be caused by more mineralized water moving up from great depths.

Within the area a narrow belt underlain by shale and sandstone contains highly mineralized ground water at some places. This belt is underlain by rocks of the Sonyea and Genesee Formations (fig. D-2) with which this water is probably associated. Whether these rocks actually are the source of the dissolved solids is uncertain. Highly mineralized water, discharging from great depths, may be moving up through these rocks and increasing the average concentration of dissolved solids in the ground water in this belt. The quality of the water in the eastern part of the Genesee and Sonyea Formations has not yet been investigated.

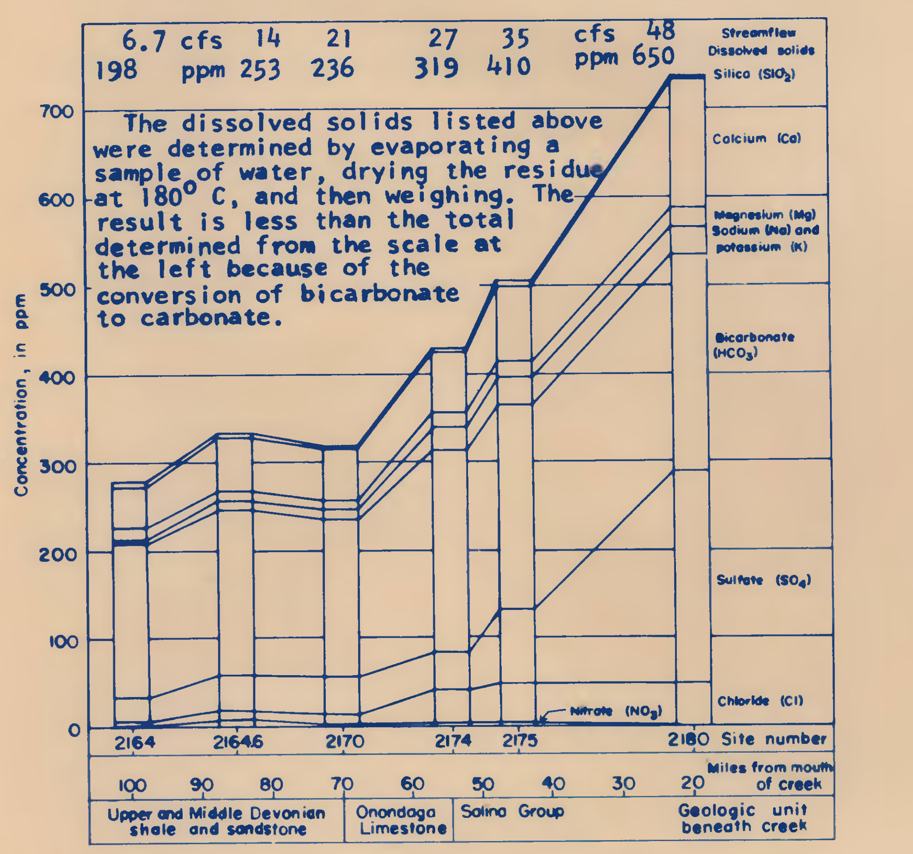

Figure F-3.--Chemical quality of water in Tonawanda Creek at six sites during low streamflow, July 2, 1963.

The glacial deposits yield water that generally is less mineralized than that in the underlying rocks (table F-2). The water in the glacial deposits overlying the Salina Group is highly mineralized and therefore of poor quality, though less mineralized than that in the bedrock. On the other hand, the water in the glacial deposits overlying the shale and sandstone is of good quality at many places in the south-central and southeastern part of the area. The glacial deposits generally do not contain easily soluble minerals in so great abundance as the bedrock. The rock materials composing the glacial deposits are generally derived from the underlying rocks, but the materials have been leached of more soluble minerals.

The water from shallow wells tapping the glacial deposits tends to be less mineralized than water from deeper wells in the same deposits. The ground water in the glacial deposits is a mixture of water that directly infiltrated the deposits and of water that moved into the deposits from the bedrock. Shallow wells yield water with low concentrations of dissolved solids, probably because part of the water in the glacial deposits circulates to only shallow depth and moves relatively short distances to these wells or other points of discharge. Deeper wells in the glacial deposits located in valleys generally yield more mineralized water than the shallow wells. The deeper wells not only intercept ground water that travels deeper and farther, but probably also intercept some water that moved into the deposits from the bedrock.

The sand and gravel deposits capable of yielding large supplies of ground water (fig. C-1) contain water that generally ranges from about 50 to 400 ppm in hardness and 100 to 600 ppm in dissolved solids. Iron is a problem in some of these deposits but chloride and sulfate concentrations are low. Some of the glacial deposits in the upper Cattaraugus Creek valley and the South Branch Cattaraugus Creek valley contain water that is less than 120 ppm in hardness.

The quality of the water yielded by a well depends greatly on the geologic environment in the vicinity. When a well is pumped at a high rate the area from which water is drawn increases progressively. As pumping continues the quality of the water produced by the well may change as water of different quality is drawn from farther and farther away. For instance, if infiltration eventually is induced from a stream, the quality of the water produced by the well will approach that of the stream. Figure F-1 shows by patterns the regional characteristics of quality of shallow ground water in the area. The patterns were drawn on the basis of stream sampling from July 2-5, 1963. During this period the streams were at low flow and therefore the flow was almost entirely from ground-water discharge. The samples represent, therefore, the average quality of shallow ground water discharging to the streams and probably the average quality of the ground water that can be developed on a long-term large-scale basis.

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The State Department of Health has a primary interest in the surveillance of water quality in New York. That department is cooperating with the U. S. Geological Survey by making available data and performing analyses relating to the chemical quality of the waters of the region. Data and information on sanitary aspects, which are the responsibility of the State Health Department, are not included in this preliminary appraisal, but will be included in the report to be prepared by the Geological Survey at the conclusion of Phase 2 of the Lake Erie-Niagara study.

WATER RESOURCES OF THE LAKE ERIE-NIAGARA AREA

A PRELIMINARY APPRAISAL

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY — WATER RESOURCES DIVISION

NEW YORK STATE WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

SHEET G—SEDIMENT IN STREAMS AND SUMMARY OF WATER RESOURCES

SUSPENDED SEDIMENT IN STREAMS

One of the natural characteristics of a stream is that it carries materials in suspension, such as clay, silt, and sand. Some of this suspended sediment has been eroded by the stream from its own bed and banks. Additional quantities of sediment are carried into a stream by overland flow eroding land surfaces, especially where hills are steep and there is little or no vegetation. Man increases the supply of sediment when he scrapes away or loosens the soil during construction activities or when he overturns the soil during plowing. Suspended sediment in a stream at one point may later be redeposited downstream if the stream velocity becomes too low to retain the materials in suspension.

As a general rule, both concentration and load of sediment increase when streamflow increases, but this is not always true, and there are wide variations in sediment concentration from place to place and from one time to another. However, since the highest streamflows usually occur from snowmelt or rains of early spring, the highest sediment loads also usually occur in the spring. Figure G-1 shows the stream discharge and sediment load of Cattaraugus Creek at Gowanda between March 25 and 27, 1963. The high stream discharge in this case was a result of the melting of the last 12 to 15 inches of snow remaining on the ground from winter snowfalls.

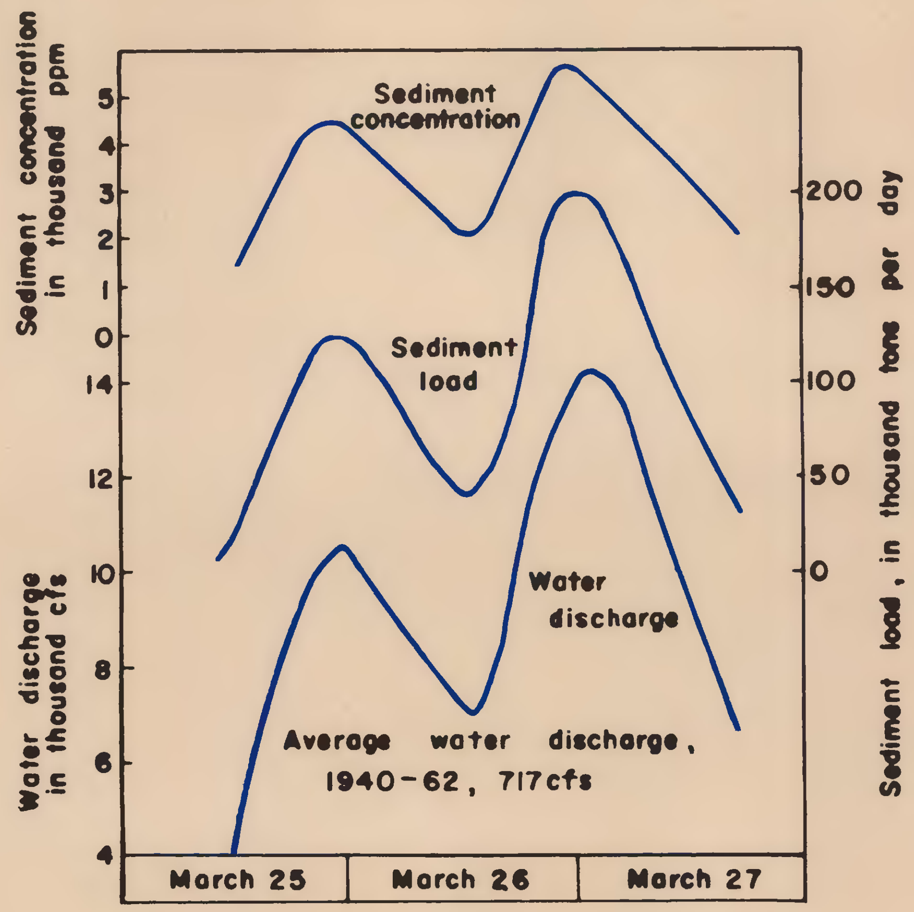


Figure G-1.--Water discharge and sediment load and concentration in Cattaraugus Creek at Gowanda, March 25-27, 1963.

Sediment is a problem and expense for the water user, because the particles of sediment must be removed before the water is suitable for municipal and most industrial uses. Accumulations of deposited sediment sometimes also become problems in harbors and behind dams. One of the principal sediment problems in the Lake Erie-Niagara area is in the harbor at Buffalo. The Buffalo River reportedly deposits more than 100,000 tons of sediment a year in the harbor. Dredging is required to maintain the harbor for navigation.

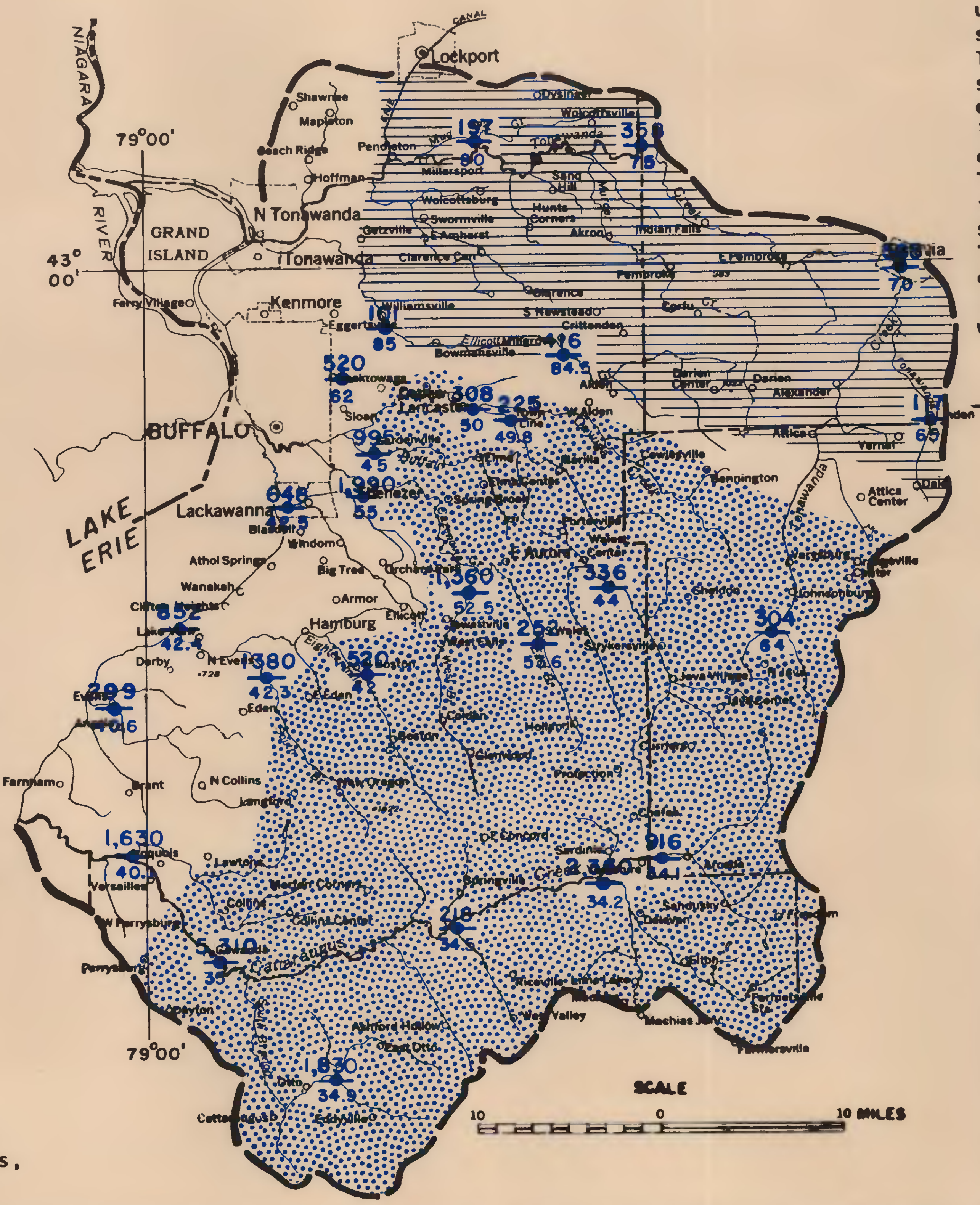
In 1963 the U.S. Geological Survey made a sediment reconnaissance of the Lake Erie-Niagara area, mainly during times of relatively high streamflow. Sediment concentrations, in ppm (parts per million), were determined for 26 stream sites (fig. G-2 and table G-1). The sediment analyses show relatively high concentrations in many of the streams, especially in the southern and central parts of the region.

A preliminary computation of average annual sediment loads, in tons per year, was made for 9 sites at which continuous streamflow records have been obtained for at least 7 years. These data were then evaluated in terms of topography and other factors, and presented in generalized form on figure G-2. The highest loads are carried by streams draining the central and southern uplands, and the lowest loads by streams flowing through the relatively flat-lying areas in the central part of the Tonawanda Creek basin. In fact, in that area, more sediment is being deposited than is being eroded, if the limited records of 1963 are reasonably typical of conditions there.

In addition to the sediment concentrations measured by the Survey in 1963, the following maximum measured values were recorded for the period 1953-61 by the U.S. Department of Agriculture, Agricultural Research Service and Soil Conservation Service, at 3 sites:

- Buffalo Creek at Gardenville (site 2145), 8,970 ppm at discharge of 8,500 cfs, May 26, 1953.
- Cayuga Creek near Lancaster (site 2150), 5,330 ppm at discharge of 4,550 cfs, Apr. 2, 1959.
- Cazenovia Creek at Ebenezer (site 2155), 5,560 ppm at discharge of 6,500 cfs, Apr. 2, 1959.

It is important to note again that the maximum concentrations and loads of sediment occur during periods of high streamflow. Since these periods of high flow are relatively short, much lower concentrations and loads are a more normal occurrence. From the results of additional sampling of sediment the magnitude and probable frequency of occurrence of lesser sediment concentrations may be computed.



1,830
34.9 — Maximum measured concentration of suspended sediment, in ppm, in samples collected during 1963
Site number 2134.9 ("21" omitted from all numbers shown above)

Estimate of average annual sediment load, in tons per year per square mile: Less than 100 | 100—500 | 500—1,500

Figure G-2.--Maximum sediment concentrations at selected sites during 1963, and estimated average annual sediment loads.

SUMMARY OF WATER RESOURCES

The water resources of the Lake Erie-Niagara area are large and can more than meet the anticipated water needs of the next 50 to 100 years. To meet these needs, further development of the available water resources will be required for public water supplies, industries, agricultural irrigation, and individual domestic supplies. Lake Erie and the Niagara River now supply most of the water used in the area, these sources providing more than 200 mgd (million gallons per day) for public supplies and more than 150 mgd for industrial use. About 150 mgd is pumped from streams (other than the Niagara River) and wells for public and industrial supplies. Only a small part of the total use is consumptive. Most of the water is returned after use to the streams or to Lake Erie.

Average precipitation in the area ranges from 31 inches in the northern part to 44 inches in the southern part of the area. Average runoff, or the water discharged through streams, ranges from about 15 inches in the northern part to 24 inches in the southern part; equal to a region-wide streamflow (excluding the Niagara River) averaging 1,750 mgd. The streamflow represents the water discharged from the area to Lake Erie or the Niagara River by both overland runoff and ground-water discharge.

The water normally discharged from the area can be utilized in two ways -- withdrawing it directly from the streams and withdrawing it from the ground through wells. The flow and chemical quality of stream water varies seasonally. Streamflow is greatest and has the best chemical quality in the spring. Streamflow then declines to very low rates that are maintained throughout the summer and early fall, except for temporary increases due to rain. The water in the streams at low flow during the summer contains significantly higher concentrations of dissolved solids than does the water during high flow in the spring. The water at low flow is almost entirely ground-water discharge, and the chemical quality of this water is therefore largely controlled by the geologic environment through which the water has moved.

Table G-1.--Maximum suspended sediment concentrations measured in 1963

Site number	Name of creek (At or near place listed)	Drainage area at site (sq mi)	Number of measurements made	Maximum measured sediment concentration (ppm)	Water discharge[1] (cfs)	Date in 1963
2134.1	Cattaraugus (Arcade)	79.1	4	916	1,500	Mar. 27
2134.2	Elton (The Forks)	71.1	7	2,360	1,340	Mar. 25
2134.5	Buttermilk (Springville)	29.3	2	218	169	Apr. 20
2134.9	South Branch Cattaraugus (Otto)	25.6	3	1,830	538	Mar. 26
2135	Cattaraugus (Gowanda)	428	10	5,310	13,000	Mar. 26
2140.1	Clear (Iroquois)	56.4	3	1,630	1,290	Mar. 26
2140.6	Big Sister (Evans Center)	48.4	1	299	187	Apr. 19
2142	Eighteenmile (North Boston)	37.2	9	1,520	577	Apr. 19
2142.3	South Branch Eighteenmile (Eden Valley)	36.3	1	1,380	720	Apr. 19
2142.4	Eighteenmile (Highland-on-the-Lake)	119	2	852	1,160	Apr. 19
2142.5	Smoke (Lackawanna)	14.6	1	648	270	Aug. 7
2144	Buffalo (Wales Hollow)	80	3	336	770	Apr. 20
2145	Buffalo (Gardenville)	145	2	995	2,270	Apr. 4
2149.8	Little Buffalo (East Lancaster)	23.9	1	225	96	Aug. 7
2150	Cayuga (Lancaster)	93.3	1	308	527	Aug. 7
2152.5	West Branch Cazenovia (East Aurora)	56.6	2	1,360	775	Apr. 19
2153.5	East Branch Cazenovia (South Wales)	38.0	3	252	663	Mar. 25
2155	Cazenovia (Ebenezer)	136	3	1,990	1,570	Aug. 7
2162	Scajaquada (Buffalo)	15.7	4	520	122	Apr. 4
2164	Tonawanda (Johnsonburg)	24.6	2	304	450	Mar. 26
2165	Little Tonawanda (Linden)	22.0	7	117	469	Apr. 4
2170	Tonawanda (Batavia)	172	11	585	1,210	Mar. 25
2175	Tonawanda (Alabama)	230	6	358	1,730	Apr. 5
2180	Tonawanda (Rapids)	358	9	197	2,890	Mar. 27
2184.5	Ellicott (Mill Grove)	40.6	9	416	528	Apr. 4
2185	Ellicott (Williamsville)	76.3	12	101	508	Apr. 4

[1] Discharge at time of maximum sediment concentration.

Large supplies of ground water can be developed from the more permeable ground-water reservoirs in the area. Ground-water availability, quality, and temperature vary little with the seasons.

The availability and chemical quality of the water resources vary areally. For example, the water resources in the valleys of the Appalachian Uplands in the central, southern, and eastern parts of the area offer the best possibilities for large-scale development. These parts of the area are, at present, sparsely populated in comparison with the industrialized northwestern part. They are also the most difficult parts into which to transport water from Lake Erie because of distance from and height above Lake Erie. Perennial streamflow and ground-water discharge are largest in some of the valleys of the Appalachian Uplands, particularly in the Cattaraugus basin. The better ground-water reservoirs are sand and gravel deposits capable of yielding up to 1,200 gallons per minute to individual wells. Some of these deposits in the valleys occur in the vicinity of Arcade, Sardinia, and Springville. Only small supplies of water are available in the hills, which generally are underlain by rocks yielding little water to wells.

Large supplies of water might be developed in the upstream reaches of Cattaraugus, Buffalo, Cayuga, Tonawanda, and Cazenovia Creeks, and on some tributaries of Cattaraugus Creek, by storing some of the high streamflow that occurs in early spring. The quality of such water probably would approach the chemical quality of water available from Lake Erie.

The water resources north of a line between Buffalo and Batavia have serious drawbacks to extensive development. Although the average annual streamflow of Tonawanda Creek is large (exceeded in the Lake Erie-Niagara area only by Cattaraugus Creek), perennially dependable supplies from the northern part of Tonawanda Creek are generally limited by the low flows of summer. Much greater development of that part of the creek is probably impractical because of the lack of suitable reservoir sites in the relatively flat terrain west of Batavia. Ground water in this northern area is available in large supplies from the Salina Group, but is too highly mineralized for general use. Discharge of this mineralized water from the ground substantially raises the dissolved-solids content of the creek during low flow.

Industrial wastes severely pollute the Buffalo River and reaches of Cattaraugus and Smoke Creeks. Particularly objectionable constituents sometimes contained in the wastes are phenol and chromium. Septic tank wastes in populated areas that are unsewered are potential sources of pollution to shallow ground water.

The sediment loads of streams in the Appalachian Uplands are large during high streamflow. However, the streams carry large amounts of sediment only for short periods of time. The sediment must be removed for some uses of water, such as public supplies. Accumulations of deposited sediment sometimes also become problems in harbors and behind dams.

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The U.S. Geological Survey studies in the Lake Erie-Niagara area are being carried out under the leadership of A. M. LaSala, Jr., and under the general supervision of R. C. Heath, district geologist. W. E. Harding and R. J. Archer are responsible for the surface-water and quality-of-water parts of this water-resources investigation.